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ENERGY SECURITY IN SINGAPORE

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ENERGY SECURITY IN SINGAPORE

by

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13. ABSTRACT (maximum 200 words)

This thesis examines Singapore's current energy policy and addresses how it is helping the country achieve greater energy security. Using a strengths, weaknesses, opportunities, and threats (SWOT) analysis approach, the three energy sub-sectors of hydrocarbons, nuclear energy, and renewables are evaluated to determine how Singapore’s core policy complements its energy security ambitions. The thesis concludes that Singapore need not possess a large endowment of domestic energy resources to enhance its energy security, as this can be achieved through partnership with international players, a whole-of-government approach, technical innovation, and perseverance in bridging the energy gap. With regard to the increasingly competitive international energy environment, Singapore need not take drastic measures to modify its current energy framework. Despite its lack of indigenous natural resources, Singapore will survive in a world of heightened energy demands by focusing on managing its foreign relations, because the future of energy security depends on positive ties between countries that participate in the global energy system.

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ENERGY SECURITY IN SINGAPORE

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Submitted in partial fulfillment of the
requirements for the degree of

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LIST OF ACRONYMS AND ABBREVIATIONS

ASEAN	Association of Southeast Asian Nations
BIPV	building-integrated photovoltaic
CCGT	combined-cycle gas turbine
CO2E/GWH	carbon dioxide equivalent per gigawatt hour
CSR	corporate social responsibility
EIA	Energy Information Administration
EMA	Energy Market Authority
EPG	Energy Policy Group
ESC	Economic Strategies Committee
GHG	greenhouse gas
IAEA	International Atomic Energy Agency
IES	Intelligent Energy System
IMCSD	Inter-Ministerial Committee for Sustainable Development
LCOE	levelized cost of energy
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MEWR	Ministry of the Environment and Water Resources
MMBTU	one million British thermal units
MOF	Ministry of Finance
MTI	Ministry of Trade and Industry
MWE	megawatt electrical
MWP	megawatts peak
NCCS	National Climate Change Secretariat
NEA	Nuclear Energy Agency
NEPR	National Energy Policy Report
NSREP	Nuclear Safety Research and Education Program
NUS	National University of Singapore
PMET	professionals, managers, executives, and technicians
PNG	piped natural gas
PV	photovoltaic

R&D	research and development
SEAS	Sustainable Energy Association of Singapore
SNSRI	Singapore Nuclear Research and Safety Initiative
SWOT	strengths, weaknesses, opportunities, and threats
WTE	waste-to-energy

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I. INTRODUCTION

A. MAJOR RESEARCH QUESTION

Singapore is a geographically small country with limited natural and energy resources. As such, Singapore depends on foreign supplies of oil and natural gas to meet its domestic energy requirements, which exposes the energy industry to supply chain disruptions. Between 2007 and 2010, the Singapore government published three major documents outlining its vision and strategy on the growing energy challenge. Within these documents, the government identifies energy diversification as one key strategy to help achieve the country's overarching objectives of economic competitiveness, energy security, and environmental sustainability.[1] Considering the three major energy subsectors of hydrocarbons, nuclear power, and renewables, in what way is Singapore's current energy strategy helping the country achieve greater energy security? How might Singapore modify its energy policy given that international competition for energy sources has intensified?

B. SIGNIFICANCE OF THE RESEARCH QUESTION

Since its independence, Singapore owes much of its meteoric economic growth to the energy industry. Over the past 50 years, the country has invested in oil refineries, petrochemical plants, marine bunkers and storage facilities, and continues to attract foreign investors due to its strategic location astride the oil trade route in Southeast Asia. Despite its lack of domestic energy resources, Singapore successfully secures adequate energy supplies to support its highly urbanized population. Even more impressive, the country has learned to transform its resource deficiencies into business opportunities and thereby made its economy one of the strongest in the region.

Singapore's past 50 years of affluence, however, do not guarantee that it will reap the same dividends in the future. Concepts such as peak oil—the idea that the world's

[1] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report" (Singapore Ministry of Trade and Industry, 2007), 5.

oilfields will soon reach a maximum rate of extraction—and the susceptibility of energy supplies to natural disasters, sabotage, terrorism, embargoes, and political conflict all threaten the survival of any country relying on fossil fuels as their main source of energy. Therefore, the Singapore government must assess its current energy policy against the country's capability and strategy to achieve their goals of energy independence. Significantly for a nation with no indigenous energy supplies, matching strategy with policy prevents wasted human capital and financial resources.

In addition, Singapore should observe the trends and study the implications of the intensifying global competition for natural resources to secure the future of its own energy supply. A small city-state like Singapore does not have enough political influence and leverage to use during an energy crisis. Therefore, Singapore's planners and policymakers need to draft strategies that will keep the country ahead of the global energy competition.

C. LITERATURE REVIEW

Between 2007 and 2010, the Singapore government published three major documents outlining its vision and strategy on the growing energy challenge: the first, known as the *National Energy Policy Report (NEPR)*, was released in October 2007 and calls for a holistic approach that balances the overarching objectives of economic competitiveness, energy security, and environmental sustainability.[2] This approach reflects Singapore's understanding of the energy trilemma, a concept introduced by the World Energy Council that defines energy independence according to the "three core dimensions —Energy Security, Energy Equity, and Environmental Sustainability."[3] Authored by the Energy Policy Group (EPG) under the leadership of the Ministry of Trade and Industry (MTI), the NEPR outlines hard targets for Singapore's energy industry to increase its value-add from "$20 billion to around $34 billion by 2015, and to triple the employment generated from 5,700 to 15,300."[4]

[2] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 5.

[3] World Energy Council, "World Energy Trilemma Index 2018" (United Kingdom, 2018), 9, https://www.worldenergy.org/assets/downloads/World-Energy-Trilemma-Index-2018.pdf.

[4] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 8.

In April 2009, the Inter-Ministerial Committee for Sustainable Development (IMCSD), the Ministry of National Development, and the Ministry of Environment and Water Resources (MEWR) released its strategy for sustainable development. The *Sustainable Development Report* revises the NEPR's employment and value-add hard targets to 18,000 jobs and US$2.5 billion.[5] At the same time, the MEWR formulated its definition of sustainable development as advancing the economy in an efficient, clean, and green way by utilizing fewer resources, minimizing waste production, and preserving natural heritage. A year later, the government fine-tuned the existing energy strategy in a document released by the Economic Strategies Committee (ESC) under the leadership of the Ministry of Finance (MOF).[6] The *Smart Energy Economy Report* recommended measures for Singapore to become energy resilient, sustainable, and innovative, with a particular focus on technology to help overcome its energy challenges.

Despite Singapore's cognizance of the energy trilemma and the government's three-pronged approach to addressing the country's energy challenges, some believe that Singapore's overall energy framework is in fact one-dimensional. Ng, for instance, argues that where energy is concerned, Singapore is pre-occupied with obtaining supplies cheaply to sustain its long-term economic growth.[7] She further claims, "The ethical, ecological, social and environmental dimensions of a truly holistic policy are not found in the documents."[8] Similarly, Youngho and Putra believe that unlike most nations, Singapore's energy policy emphasizes economic development and advocates for the transformation of resource deficiencies into profitable opportunities.[9] All these critics seem to agree on the

[5] Weng Hoong Ng, *Singapore, the Energy Economy* (Abingdon, England: Routledge, 2012), 218. Note: This document was updated in 2015, but with no reference to the employment and value-add targets stated in the initial policy.

[6] Kwong Hwa Jen and S Iswaran, "ESC Subcommittee on Ensuring Energy Resilience and Sustainable Growth" (Economic Strategies Committee, February 2010), 84, https://www.mof.gov.sg/Portals/0/MOF%20For/Businesses/ESC%20Recommendations/Subcommittee%20on%20Ensuring%20Energy%20Resilience%20and%20Sustainable%20Growth.pdf.

[7] Ng, *Singapore, the Energy Economy*, 3.

[8] Ng, 219.

[9] Chang Youngho and Nur Azha Putra, "Energy Security in Singapore: Challenges and Opportunities," Nanyang Technological University Singapore, accessed August 2, 2019, https://www.rsis.edu.sg/rsis-publication/nts/1121-energy-security-in-singapore/#.XUSSjZNKj-Z.

same observation—in terms of managing the energy trilemma, Singapore prioritizes its economic performance over energy security and environmental sustainability.

There is some veracity to their critique as Singapore's governmental determination and actions have led to various economic achievements in the energy sector. To illustrate, Singapore is a major crude oil refiner with a daily production capacity of 1.3 million barrels; most of Singapore's oil refineries are running at full capacity, designed to refine crude oil from the Middle East.[10] Singapore is also the world's leading bunkering port, supplying 40.6 million tonnes of fuel to ships and exceeding US$20 billion in bunker sales in 2010.[11] In addition, Singapore is the world's third-largest oil trading center, and its physical oil trade reached US$188 billion in 2004, equivalent to about 20 percent of the global oil business.[12]

Others believe that despite Singapore's economics-driven energy policy, Singapore has performed strongly in the area of environmental sustainability. For example, Singapore is recognized as Asia's greenest city despite its highly urbanized and dense population, partly owing to its national policies and the government's ability to execute and enforce those regulations and standards.[13] Likewise, academics and urban environmental sustainability experts have praised Singapore's green growth track record, naming Singapore as a best practice case study in Asia and abroad.[14] Tan argues:

> For Singapore, it was never a case of pursuing growth at all costs and cleaning up afterwards. Investing in the environment continues to be of high priority today…[t]he Singapore Government has always made clear to the

[10] Mark Hong, "Overview of Singapore's Energy Situation," in *Energy Perspectives on Singapore and the Region* (Singapore: Institute of Southeast Asian Studies, 2017), 2–3.

[11] Ng, *Singapore, the Energy Economy*, 159.

[12] Hong, "Overview of Singapore's Energy Situation," 3.

[13] Economist Intelligence Unit, "Asian Green City Index: Assessing the Environmental Performance of Asia's Major Cities" (Siemens, 2011), 10, http://sg.siemens.com/city_of_the_future/_docs/Asian-Green-City-Index.pdf.

[14] Economist Intelligence Unit, 12; Peter Newman, "Green Urbanism and Its Application to Singapore," *Environment and Urbanization Asia* 1, no. 2 (2010): 149, https://doi.org/10.1177/097542531000100204; Puay Yok Tan, James Wang, and Angelia Sia, "Perspectives on Five Decades of Urban Greening in Singapore," *Cities* 32 (June 2013): 24.

> public the national priority placed on the environment so that its vision for the environment can be shared and supported by everyone.[15]

While varied opinions exist on the Singapore's energy policy, most literature acknowledges that Singapore is nowhere near the world's top performers in terms of energy security. In a study of 21 APEC economies by the Asia Pacific Energy Research Center, Singapore's energy security proved disappointing relative to the country's economic sophistication.[16] Another study by Sovacool compared 18 countries from 1990 to 2010 and Singapore ranked seventh out of 18 economies in terms of energy security performance.[17] The study by the World Economic Forum ranked Singapore 39th among the 127 countries surveyed in terms of progress in achieving energy security while balancing economic growth and environmental sustainability.[18] No matter which framework or indicators are used, Singapore's energy security has often been identified as the area that requires improvement.

The complex relationship between energy security, energy equity, and environmental sustainability is best illustrated by the Energy Trilemma Index in Figure 1. This scorecard shows that over the years, Singapore has consistently performed well in the realms of energy equity and environmental sustainability, but has slipped in the domain of energy security. Furthermore, this scorecard indicates that trade-offs occur between policies and strategies that are effective along one dimension but have adverse impacts on the other two.

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[15] Yong Soon Tan, *Clean, Green and Blue: Singapore's Journey Towards Environmental and Water Sustainability* (Singapore: Institute of Southeast Asian Studies, 2009), 6.

[16] Alicia Aponte et al., *A Quest for Energy Security in the 21st Century* (Tokyo, Japan: Asia Pacific Energy Research Centre, 2007), https://aperc.or.jp/file/2010/9/26/APERC_2007_A_Quest_for_Energy_Security.pdf.

[17] Benjamin K Sovacool, "An International Assessment of Energy Security Performance," *Ecological Economics* 88 (April 2013): 148.

[18] World Economic Forum, "Energy Architecture Performance Index" (Geneva, Switzerland: World Economic Forum, 2017), http://wef.ch/2jkV5HX.

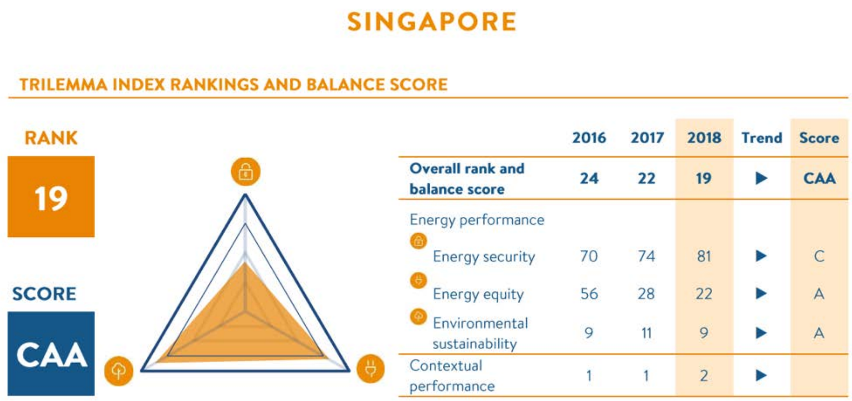

Figure 1. Energy Trilemma Index of Singapore, 2016–2018.[19]

Daniel Yergin identifies diversification of energy resources as a step toward greater security and energy independence: multiplying supply sources limit the effects of disruption from a given source by providing viable alternatives.[20] By being highly dependent on imported fuels, Singapore is exposed to both supply and price risks. For instance, geopolitical conflict, terrorism, and natural disasters can lead to energy supply disruption. Consequently, oil and gas prices may rise, which can undermine Singapore's economic competitiveness.

The Singapore government acknowledges the benefit of spreading risks by tapping multiple sources of energy; therefore, all the energy policy documents identify diversification as a key strategy for enhancing energy security.[21] However, expansion of the fuel mix poses geographical, technological, and practical challenges for Singapore. For example, the national energy policy states that alternative sources of energy such as hydro,

[19] Source: World Energy Council, "Energy Trilemma Country Profile: Singapore," World Energy, accessed August 7, 2019, https://trilemma.worldenergy.org/#!/country-profile?country=Singapore&year=2018.

[20] Daniel Yergin, "Ensuring Energy Security," *Foreign Affairs* 85, no. 2 (2006): 69–82, https://doi.org/10.2307/20031912.

[21] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 31; Jen and Iswaran, "ESC Subcommittee on Ensuring Energy Resilience and Sustainable Growth," 86; Ministry of Foreign Affairs, "Towards a Sustainable and Resilient Singapore" (Singapore: Ministry of Foreign Affairs, 2018), 24–25, https://sustainabledevelopment.un.org/content/documents/19439Singapores_Voluntary_National_Review_Report_v2.pdf.

geothermal, wind power, and nuclear energy are not available in Singapore due to the country's dense and urban landscape. Solar power is encouraged, but is costly compared to conventionally-produced electricity. Energy from coal has potential but faces environmental and health concerns.[22] Nevertheless, Singapore remains optimistic regarding diversification away from oil and gas sources. The NEPR articulates, "we should keep all energy options on the table. As technology improves, energy sources which are not feasible for Singapore today may become viable in the future."[23]

Accordingly, the potential areas in which Singapore can expand its domestic energy production and enhance energy independence can be divided into three subsectors: hydrocarbons, nuclear, and renewables. Hydrocarbon fuels include oil, natural gas, and coal. In 2017, Singapore's fuel mix consisted of natural gas (95.2%), petroleum (0.7%), coal (1.3%), and other energy products such as solar, waste, and biomass (2.9%).[24] Although dependence on fuel oil for electricity generation has declined over the years, Singapore's fuel composition lacks the diversity seen in the global energy landscape.

As the most urbanized country in Southeast Asia, Singapore is expected to consume increased amounts of energy in the future. Thus, the Energy Market Authority (EMA) projects a continued heavy reliance on natural gas to meet the increasing electricity demand.[25] In 2013, Singapore opened its first liquefied natural gas (LNG) terminal to import natural gas from different sources around the world. This project was a strategic move away from dependence on gas pipelines coming from Malaysia and Indonesia.[26] Although LNG supports the fuel diversification strategy, it does not reduce the reliance on

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[22] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 7.

[23] Ministry of Trade and Industry, 32.

[24] Energy Market Authority, "Singapore Energy Statistics 2018," 2018, 14, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Publications/SES18/Publication_Singapore_Energy_Statistics_2018.pdf.

[25] Energy Market Authority, "Preparing for Future Power Generation Investments in Singapore," December 21, 2015, 9, https://www.ema.gov.sg/cmsmedia/Consultations/Electricity/Consultation%20Paper%20-%20Preparing_for_Future_Power_Generation_Investments_in_Singapore.pdf.

[26] Singapore LNG Corporation, "Importance of LNG to Singapore," accessed August 7, 2019, https://www.slng.com.sg/website/content.aspx?wpi=Importance+of+LNG+to+Singapore&mmi=27&smi=117.

hydrocarbons as the primary energy source for the power sector. Even former Prime Minister Lee Kuan Yew was less optimistic regarding the expansion of the fuel mix when he stated, "Singapore would never become fully energy-independent, and it would never be able to generate enough energy from renewable sources like solar or wind to power its economy."[27]

Some have proposed nuclear power as a future energy source to mitigate the effects of global warming and the rising oil, gas, and coal prices. One particular appeal of this technology is that the fission process does not release CO2 to the atmosphere, making nuclear power a low-carbon energy source. In addition, nuclear power can be cost-competitive in the long run despite its higher upfront costs.[28] In 2010, the ESC recommended nuclear research to begin immediately as "the process of developing nuclear energy, if deemed feasible, is likely to take at least 15 years."[29] Following this recommendation, the MTI conducted a feasibility study to examine the safety, technical, and economic viability of nuclear technology.[30] The study determined that the introduction of nuclear energy in Singapore is not yet advisable due to the safety and security risks it presented to its dense urban population.

Meanwhile, other scientists and engineers have shifted the dialogue from whether Singapore should consider nuclear power, to instead consider where it should establish its new energy source. For example, Palmer et al. advocate for an underground nuclear power station because it minimizes the risks of a nuclear accident and risks associated with the theft, smuggling, and misuse of nuclear substances.[31] Buongiorno et al. suggest an offshore floating nuclear plant because it eliminates the threat of earthquakes and tsunamis and does

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[27] Ng, *Singapore, the Energy Economy,* 219.

[28] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 32.

[29] Ng, *Singapore, the Energy Economy,* 127.

[30] Ministry of Trade and Industry, "Factsheet Nuclear Energy Pre-Feasibility Study," 2012, 1, https://www.mti.gov.sg/-/media/MTI/Newsroom/Parliament-QandAs/2012/10/Second-Minister-S-Iswarans-reply-to-Parliament-Questions-on-nuclear-energy-pre-feasibility-study-in-/pre-fs-factsheet.pdf.

[31] Andrew Palmer, Seeram Ramakrishna, and Hassan Muzaffar Cheema, "Nuclear Power in Singapore," *The IES Journal Part A: Civil & Structural Engineering* 3, no. 1 (February 1, 2010): 68, https://doi.org/10.1080/19373260903343449.

not commit the country to a long-term project unlike indigenous nuclear infrastructures.[32] Amidst this unsettled debate, Singapore is not ruling out nuclear power as a possible source of energy for the small island-nation. In 2014, the government announced that it will bolster its nuclear technology expertise by launching a Nuclear Research and Education Programme with the oversight of the National Research Foundation.[33] The initiative was granted an initial budget of US$63 million with the objective of developing a community of nuclear experts and capabilities in nuclear safety, science, and engineering.

In an effort to further diversify its energy mix and to address the issue of environmental sustainability, Singapore began promoting the renewable energy sector after acceding to the Kyoto Protocol, which it signed in July 2006. However, some analysts are doubtful regarding the renewable energy plan. For instance, Ng points out that "the government has launched several ambitious initiatives all at the same time that demand detailed and intricate coordination across various agencies."[34] Hamilton-Hart writes, "I have not found a single policy target or statement by MEWR or the NEA that targets absolute cuts in Singapore's emissions."[35] The National Climate Change Secretariat (NCCS) claims there are limits to how much more the country can reduce its greenhouse gas emissions, given that Singapore has already shifted 95% of its fuel mix to natural gas, which is a cleaner form of fossil fuel compared to coal and oil.[36]

Despite the claims by the NCCS, Singapore continues to tap renewable sources of energy to improve its energy security. For example, large-scale solar photovoltaic panels are being installed nationwide, with the goal of providing 350 megawatts peak (MWp) of

[32] J Buongiorno et al., "The Offshore Floating Nuclear Plant Concept: Nuclear Technology: Vol 194, No 1," *Nuclear Technology* 194, no. 1 (2016): 1, https://www.tandfonline.com/doi/abs/10.13182/NT15-49?src=recsys.

[33] Lui Pao Chuen, "Singapore Nuclear Safety Research and Education Programme" (Da Nang, Vietnam, August 5, 2015), 1–2, https://inis.iaea.org/collection/NCLCollectionStore/_Public/47/065/47065306.pdf?r=1&r=1.

[34] Ng, *Singapore, the Energy Economy*, 180.

[35] Natasha Hamilton-Hart, "Singapore's Climate Change Policy," *Innovation: The Singapore Magazine of Research, Technology, and Education*, accessed August 16, 2019, https://www.innovationmagazine.com/volumes/v9n1/coverstory4.html.

[36] National Climate Change Secretariat, "Reducing Emissions," accessed August 16, 2019, https://www.nccs.gov.sg/climate-change-and-singapore/reducing-emissions/reducing-emissions.

electricity by 2020.[37] For the long term, Singapore is looking into solar energy supplied from Australia via undersea cables. The project can potentially provide three gigawatts of electricity, or one-fifth of Singapore's electricity demand.[38] Biomass represents another alternative energy source for Singapore, wherein solid waste is directed to waste-to-energy plants for incineration. Steam produced from incinerable waste runs turbine generators, which in turn produce electricity.[39]

Energy diversification options are limited for a resource-constrained economy like Singapore, and this limitation complicates energy policy formulation. This thesis assesses the applicability of Singapore's energy framework in achieving energy security and addresses how Singapore could adapt to the world's increasing competition for natural resources while managing the energy trilemma.

D. POTENTIAL EXPLANATIONS AND HYPOTHESES

The major issue addressed by this thesis is Singapore's current energy policy and how it is helping the country achieve greater energy independence, particularly given the intensifying international competition for energy sources. Building on the available literature presented in the previous section, this thesis advances two hypotheses related to the research question.

First, I hypothesize that Singapore's collective energy policy and strategy are complementary and coincide with the country's overall energy security goals. This hypothesis is based on the observation that despite indigenous resource constraints and geographic limitations, Singapore continues to innovate and successfully invest in alternative sources of energy to improve its fuel mix. For example, the country's push for solar energy to reach up to 20% of electricity generation by utilizing water reservoirs as

[37] National Climate Change Secretariat, "Singapore's Approach to Alternative Energy," accessed August 16, 2019, https://www.nccs.gov.sg/climate-change-and-singapore/national-circumstances/singapore's-approach-to-alternative-energy.

[38] Sun Cable Singapore, "Renewable Energy for Singapore and Australia," accessed August 16, 2019, https://www.suncable.sg.

[39] National Environment Agency of Singapore, "Solid Waste Management Infrastructure," accessed August 16, 2019, https://www.nea.gov.sg/our-services/waste-management/waste-management-infrastructure/solid-waste-management-infrastructure.

additional locations for solar panel installation and by collaborating with Australia for a transoceanic solar energy supply indicates a strong commitment to energy diversification by transitioning away from fossil fuels.

Second, I hypothesize that although Singapore is on track to obtaining energy security through diversification, there are areas for improvement in the country's energy policy that may reduce volatility in foreign oil and natural gas supplies to a tolerable level roughly half of the current. Foreign energy resources reflect much volatility, and a country that imports almost 100% of its energy resources needs to understand the impact of regional tensions, energy competition, natural disasters, and embargoes on its energy portfolio.

E. RESEARCH DESIGN

This thesis adopts the research design of John Steiner, a former student at the Naval Postgraduate School and author of the graduate thesis "Energy Security in Jordan."[40] To answer the research question, this thesis accomplishes the following three tasks. First, it establishes the overall energy policy and strategy of the government of Singapore. Second, it evaluates whether the national policy and strategy complement the country's energy security ambitions. Finally, it identifies potential areas for improvement and offers recommendations on how Singapore could respond to the intensifying global demand for natural resources.

To meet the first goal, the thesis draws from a variety of sources to establish Singapore's overall energy strategy and policy. The researcher proposes that taking Singapore's core policy document at face value risks overlooking the country's whole-of-government approach and the changes made to policy and legislation since the initial national energy framework was published in 2007. For instance, Singapore initially ruled out nuclear power as an alternative energy source due to the risks associated with the country's limited land area and high population density. However, this decision was retracted when the government announced that it will bolster its nuclear technology expertise by launching a Nuclear Research and Education Programme in 2014. This deviation from the original energy framework is not captured through a written policy

[40] John R. Steiner, "Energy Security in Jordan" (Monterey, CA, Naval Postgraduate School, 2015), 14–15, https://doi.org/10.21236/AD1009292.

update. Therefore, Singapore's collective energy strategy must be ascertained as it stands today, based on the government's official documents, unstated policies, and actions. This thesis also consults scholarly journals, books, analysis by international agencies, press releases and news reports.

Next, to evaluate the effectiveness of Singapore's energy framework and to offer useful recommendations on how it may respond to the increasing energy competition, this thesis adopts a strengths, weaknesses, opportunities, and threats (SWOT) analysis approach. Singapore is examined as a single case study, but the three energy subsectors of hydrocarbons, nuclear, and renewables are considered individually. This thesis includes a discussion of the economic and political implications for Singapore related to each fuel source to evaluate the effectiveness of the policy objectives.

Singapore was chosen as a topic for energy security despite its lack of indigenous natural resources, because its innovative thinking has allowed it to carefully manage the energy trilemma, making it the number one country in Asia in terms of achieving a well-balanced energy system. In addition, the Singapore case illustrates that a nation can thrive under very limited resources and can become one of the world's most successful nations.

F. THESIS OVERVIEW

This chapter provided background on Singapore's energy policy framework and varying perspectives on the government's approach to the energy trilemma. The remainder of this thesis is divided into three energy subsectors. Chapter II covers hydrocarbons, starting with oil as the foundation for Singapore's petrochemical sector. Next, it focuses on the country's recent shift from petroleum to natural gas for electricity generation. Chapter III discusses the prospect of nuclear power as an alternative energy source and related issues, such as the economics of the technology and threats to society. Chapter IV explores the status of renewable energy in Singapore's fuel mix. Finally, Chapter V synthesizes the findings from the previous chapters to assess how Singapore's energy policy is helping the country achieve greater energy security, while offering recommendations on how Singapore could respond to the intensifying global demand for natural resources.

II. HYDROCARBONS

A. OVERVIEW

Singapore's energy landscape has transformed dramatically since the pre-British Empire era. From a sleepy fishing village relying on oil lamps and wood, the country transitioned to coal power stations in the early 1900s, to the more advanced technology of today such as combined-cycle gas turbine plants (CCGTs), solar modules, and alternative fuels for transportation.[41]

Under the leadership of Lee Kuan Yew, Singapore's first prime minister, the country began its rapid urbanization and infrastructure construction in the 1960s. One of the hallmarks of that period was the government's judgment to prioritize electricity distribution to businesses over households due to limited funding and lack of indigenous energy resources.[42] The rationale was simple: electricity was not essential for households that had alternative means of survival through charcoal and gas. On the other hand, bringing electricity to the industry would increase investment, production and jobs, therefore improving the overall quality of life of Singaporeans.[43] By embracing pragmatic policies, Singapore was able to overcome its resource disadvantages and become one of the world's fastest-growing economies.

Despite its energy innovations and policies, Singapore remains dependent on imports of carbon-based fuels to meet the country's rising energy demand. As illustrated in Figure 2, about 95% of Singapore's electricity in 2019 came from natural gas and around 2% from coal and petroleum. Natural gas is mainly supplied through pipelines from Malaysia and Indonesia, whereas crude oil is mostly imported from the Middle East.[44] This heavy reliance on hydrocarbons as a fuel source is problematic on two fronts. First, the

[41] Kuang Jin Yi, *Energising Singapore: Balancing Liveability and Growth*, ed. Wu Wei Neng (Singapore: Centre for Liveable Cities Singapore, 2018), 3, https://www.clc.gov.sg/docs/default-source/urban-systems-studies/uss-energising-singapore.pdf.

[42] Yi, 9.

[43] Yi, 9.

[44] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 15–16.

lack of diversification makes Singapore vulnerable to a number of supply and price risks such as geopolitical conflict, social unrest, accidents, and natural disasters. As a result, insufficient investments in the production capacity of supplier countries can threaten the stability of energy supplies.[45]

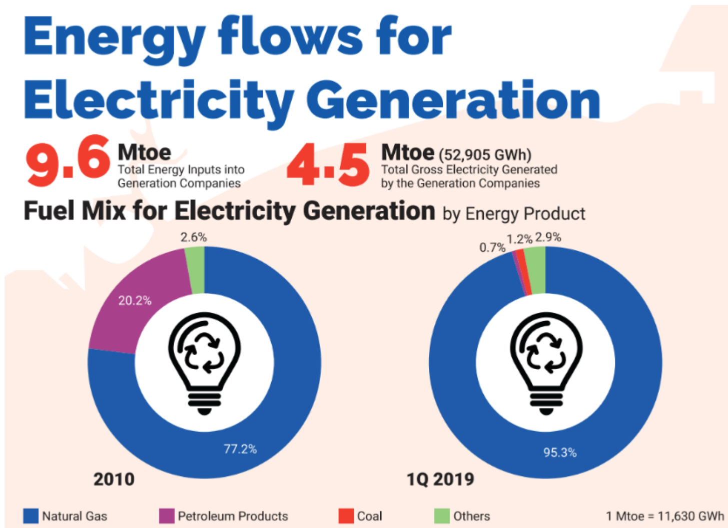

Figure 2. Singapore Fuel Mix for Electricity Generation, 1st Quarter 2019.[46]

Second, hydrocarbons threaten the environment through greenhouse gas (GHG) emissions, primarily from the burning of fossil fuels. The global concentration of carbon dioxide in 2018 was 407.4 parts per million, the maximum amount ever recorded in history.[47] For Singapore, GHG emissions are projected to continue rising steadily due to the country's economic trajectory and an energy sector that the chemical, petrochemical, and oil refining industries heavily influence.[48] If energy demand continues to be met

[45] Source: Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 15.

[46] Energy Market Authority, "Singapore Energy Statistics 2019," September 27, 2019, 2, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Publications/SES19/Infographics_Singapore_Energy_Statistics_2019_v20190927.pdf.

[47] Rebecca Lindsey, "Climate Change: Atmospheric Carbon Dioxide," Climate.gov, September 19, 2019, https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide.

[48] Climate Action Tracker, "Current Policy Projections," September 19, 2019, https://climateactiontracker.org/countries/singapore/current-policy-projections/.

mostly with fossil fuels, GHG emissions will continue to raise global temperatures and sea levels, resulting in devastating physical, economic, and social impact.

While risks of supply disruption and the growing environmental crisis call for a switch to alternative sources of energy, a complete substitution of hydrocarbons with renewables and nuclear energy is highly unlikely for a country with a long history of involvement in the oil industry. To illustrate, Singapore owes much of its prosperity to early investments in the oil subsector such as refineries, petrochemical plants, shipyards, storage terminals, oil rigs, offshore vessels, and equipment.[49] Singapore also played a vital role in the late nineteenth-century growth of major multi-national gas and oil companies, including ExxonMobil, Shell, Chevron, and British Petroleum.[50] At present, Singapore has three world-scale refineries, a liquefied natural gas (LNG) terminal, one of the world's largest oil and gas trading ports, nearly a hundred oil, gas, petrochemicals and specialty chemicals companies from the around the world, and holds 70% of the global market for oil rig building.[51] Singapore's economy is in many ways tied to the hydrocarbon industry; therefore, a divorce from this enterprise is implausible in the immediate future.

With these developments in mind, what policy options exist for "the country that oil built" to mitigate the negative impacts of supply disruption and climate change? In light of the importance of oil to Singapore's modern development, and the requisite management of the energy trilemma going forward, the country is pushing for policy initiatives that are beyond fuel diversification alone.

B. AMBITIONS

The Singapore government's policies on energy and climate change are encompassed in three national reports. The first document—the *National Energy Policy*

[49] Ng, *Singapore, the Energy Economy,* 2.

[50] Daniel Yergin, *The Prize: The Epic Quest for Oil, Money, and Power* (New York: Simon & Schuster, 1991), 67, 115–17.

[51] Swedish Trade and Invest Council, "Oil and Gas Opportunities in Singapore" (Singapore, December 2015), https://www.business-sweden.se/contentassets/ce69c7c22e71486db38e4d436d647c9d/singapore_prestudy_oil-and-gas_dec-2015.pdf.

Report (NEPR), published in 2007—outlines six strategies to balance Singapore's policy objectives of economic competitiveness, energy security, and environmental sustainability.[52] In 2009, the government released the second document—the *Sustainable Development Report*—that featured seventeen goals for 2030, ranging from the elimination of poverty to the strengthening of global partnerships for sustainable development.[53] A year later, in a third document, the government fine-tuned the existing energy strategy through the *Smart Energy Economy Report* which identified five key strategies to achieve the national energy objectives.[54]

Given the importance of hydrocarbons in Singapore's modern development as established in the previous section, it is not surprising that none of the energy policy documents provide specific goals regarding hydrocarbon reduction for domestic consumption. The three major documents published between 2007 and 2010 offer no target numbers nor a timeline for scaling down on the country's reliance on hydrocarbon products. The closest to a hard target appears in the annex of the *Sustainable Development Report* as follows: "By 2030, increase substantially the share of renewable energy in the global energy mix."[55] Thus, one needs to look beyond Singapore's core policy documents to paint an accurate picture of the government's ambitions.

Singapore has committed to major international organizations to reduce GHG emissions in an effort to combat climate change. A summary of Singapore's pledges and targets compiled by Climate Action Tracker is provided in Table 1. However, expert analysis on Singapore's commitments is rather pessimistic. According to Climate Analytics and New Climate Institute,

> Despite its high economic capacity, Singapore has a very weak climate target, which we rate as "highly insufficient," and is likely to over-achieve it without implementing any additional policies. Singapore needs to substantially strengthen its target. While renewable energy capacity has expanded, gas remains the dominant energy source in the power sector…no

[52] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 5–6.

[53] Ministry of Foreign Affairs, "Towards a Sustainable and Resilient Singapore," 3.

[54] Jen and Iswaran, "ESC Subcommittee on Ensuring Energy Resilience and Sustainable Growth," 85.

[55] Ministry of Foreign Affairs, "Towards a Sustainable and Resilient Singapore," 74.

clear policy signal to avoid locking in this carbon-intensive form of energy. Singapore started implementing a carbon tax in 2019, but its main focus for climate mitigation is on energy efficiency programmes. This will not compensate for the increasing energy demand from the industry and buildings sectors, which will result in rising emissions.[56]

Table 1. International Pledges and Targets for the Reduction of GHG Emissions.[57]

SINGAPORE	Summary of pledges and targets	
PARIS AGREEMENT	Ratified	Yes
	2030 unconditional target(s)	-36% of emissions intensity below 2005 by 2030 [154% above 1994 by 2030] [45% above 2010 by 2030]
	Coverage	Economy-wide, all GHGs covered
	Emission peak target	2030
COPENHAGEN ACCORD	2020 target(s)	Unconditional: 7–11% below BAU by 2020 [156–168% above 1994 by 2020] Conditional: 16% below BAU by 2020 [142% above 1994 by 2020]
	Condition(s)	Conditional to legally binding international agreement
LONG-TERM GOAL(S)	Long-term goal(s)	None

Furthermore, as seen in Table 1, Singapore's long-term commitments are non-existent. Unlike the European Union, the United States, and some of Singapore's Asian neighbors like Japan and Bhutan, Singapore has made no climate pledges and targets beyond 2030. Long-term goals shape the overall direction of any government or organization. In the energy and environmental sectors, long-term goals are "vital since current national climate plans are only sufficient enough to limit warming to 2.7-3.7 degrees C (4.9-6.7 degrees F). Not only do long-term strategies present an opportunity to bring national action in line with needed ambition, they also encourage countries to avoid costly investments in the wrong technologies."[58]

[56] Climate Action Tracker, "Country Summary," September 19, 2019, https://climateactiontracker.org/countries/singapore/.

[57] Source: Climate Action Tracker, "Pledges and Targets," June 17, 2019, https://climateactiontracker.org/countries/singapore/2019-06-17/pledges-and-targets/.

[58] World Resources Institute, "What is a Long-Term Strategy," accessed November 14, 2019, https://www.wri.org/climate/what-long-term-strategy.

The next section explores how Singapore's policies and actions address the three competing ends of the energy trilemma, focusing on the two main sources of hydrocarbon-based energy: petroleum and natural gas. Coal will be excluded in this discussion because its contribution to Singapore's overall energy mix is negligible.

C. PETROLEUM

The centrality of hydrocarbons in Singapore's energy policy is first evident in the NEPR strategy of promoting a competitive energy market. Part of this plan is the opening of the petroleum refining, trading, and retailing industries to business competition, making Singapore the first country in Asia to liberalize the electricity market.[59] On the positive side, the program enables businesses to set the price of electricity without subsidies, gives consumers a choice on the price plan that best meets their needs, raises economic growth potential, and encourages prudent usage of energy resources. On the negative side, the program compromises the broader energy security policy objectives when markets are unable to mitigate the negative impact of fossil fuels on the environment.[60] The strategy of liberalizing the electricity market, therefore, presents an opportunity for Singapore to rectify market failures by imposing strict standards and regulations in the energy market.

In 2001, Singapore established the Energy Market Authority (EMA) under the Ministry of Trade and Industry (MTI) to secure a reliable energy supply, promote fair competition in the energy market while protecting consumer interests, and to foster a dynamic energy sector through innovation and leadership.[61] As the energy industry developer and regulator, EMA rectifies the negative impact of fossil fuels through its "Smart Energy" and "Sustainable Future" initiatives.[62]

Singapore has also undertaken a whole-of-government approach involving different sectors and industries in formulating its energy policy. The integrated strategy of

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[59] Ministry of Foreign Affairs, "Towards a Sustainable and Resilient Singapore," 25.

[60] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 23.

[61] Energy Market Authority, "EMA: Our Roles," accessed November 15, 2019, https://www.ema.gov.sg/Our_Roles.aspx.

[62] Energy Market Authority, "EMA: Vision, Mission & Values," accessed December 2, 2019, https://www.ema.gov.sg/Vision_Mission_Values.aspx.

dealing with energy and climate change is led by the Energy Policy Group (EPG) established in 2006.[63] Members of the EPG include the MTI, EMA, Ministry of Finance, Ministry of Foreign Affairs, Ministry of the Environment and Water Resources, Ministry of Transport, and Agency for Science, Technology and Research, to name a few.[64] By bringing together various ministries and agencies, Singapore is better able to formulate solutions to a wide range of complex energy-related issues.

Another mechanism toward promoting a competitive market is Singapore's goal of securing its position as Asia's premier energy trading hub, a game plan that likewise involves continued reliance on hydrocarbons. To this end, Singapore's strategy is to build the energy industry by increasing the country's investment and output in the oil refining sector.[65] According to NEPR, Singapore will benefit economically from increasing its present refined oil production of 1.3 million barrels per day due to the growing demand in Asia. But without domestic energy resources, from which countries does Singapore procure oil? As shown in Figure 3, about 60% of Singapore's crude oil imports came from the Middle East, particularly the United Arab Emirates and Saudi Arabia. This is not surprising since a majority of the world's proven oil reserves are located in the Middle East. In effect, any major disruption in the fuel supply from the Middle East greatly upsets Singapore's petroleum industry.

[63] Green Future, "Singapore's National Policies on Energy and Climate Change," *Green Future* (blog), accessed December 2, 2019, http://www.greenfuture.sg/2009/05/14/singapores-national-policies-on-energy-and-climate-change/.

[64] Green Future, "Singapore's National Policies on Energy and Climate Change."

[65] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 25.

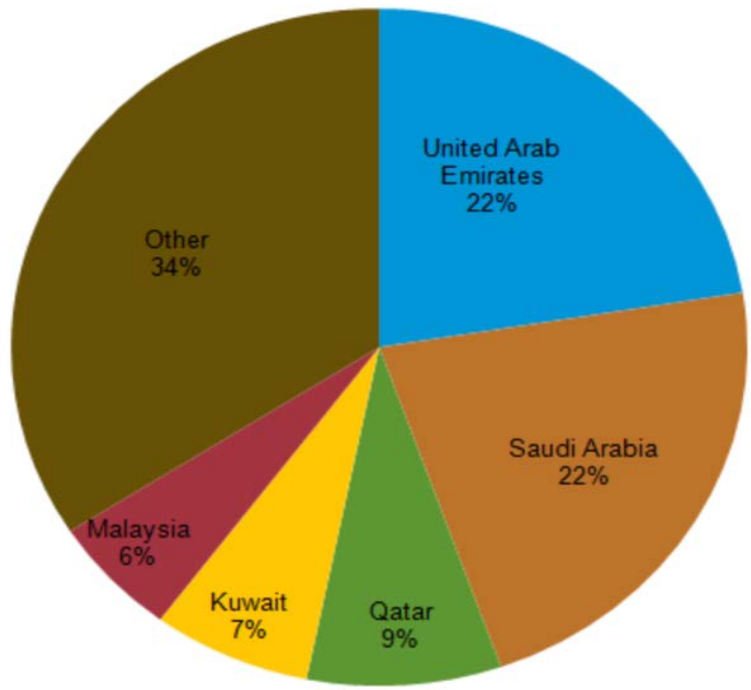

Figure 3. Singapore Crude Oil Imports by Source, 2012.[66]

Singapore's oil refining industry traces back to the country's independence from British rule and is considered the launchpad of "Singapore's economic miracle."[67] The industry brought heavy industrialization investments from the West, bolstered the credibility of the young nation and "lifted Singapore's standing in the eyes of the United States, Europe and Japan, then the world's most important powers."[68] Furthermore, Singapore's maritime trade and port traffic increased due to the development of oil refineries. Similarly, the refineries attracted investments from other industries, such as finance and banking, engineering, fuel storage and distribution, resulting in the growth of these sectors along with the expansion of the refining centers.[69]

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[66] Source: Matt Mushalik, "Security of Supplies: Crude vs Fuel Imports," *Crude Oil Peak* (blog), October 15, 2014, http://crudeoilpeak.info/sydneys-caltex-refinery-closed-as-chevrons-crude-production-and-sales-continue-to-decline.

[67] Ng, *Singapore, the Energy Economy*, 7.

[68] Ng, 8.

[69] Ng, 8–9.

Most accounts of Singapore's transition from Third World poverty to an affluent modern city-state do not give credit to how Singapore built its oil refining industry in record time. The country did not have a refinery in 1960, but by 1974 it had five operating refineries, giving Singapore the title of "Houston of Asia" because of its "petroleum-related activities [that] placed the country at the heart of the Pacific Basin's energy economy."[70]

Aside from its strategic location at the Strait of Malacca that accelerated the venture of major oil companies in the newly independent nation-state, oil refining succeeded in Singapore due to three factors: timing, liberality, and demand. According to Ng, Singapore at that time did not have competition from other countries and therefore enjoyed a first-mover advantage.[71] Second, Singapore took a less nationalistic approach and gave foreign companies complete ownership and control of their investments.[72] Third, the conflicts in Asia and the Middle East demanded fuel for military operations, which helped Singapore tighten its grip on the oil supply chain.[73]

Singapore's oil refining industry continued to develop over the next few decades, allowing the country to stay ahead of the competition. In the 1990s, Singapore started facing threats to its oil export economy. South Korea surpassed Singapore's oil production by more than twice Singapore's capacity, as Seoul supplied China's rapidly growing market.[74] By 1996, Thailand, Malaysia, Indonesia, China, and the Philippines had increased their refined oil output by 10% to rely less on imports.[75] At the turn of the century, India, China, and the Middle East launched aggressive expansion programs to build more sophisticated refineries.[76] Today, it is against this competitive environment that the Singapore government strives to secure the country's position as Asia's premier refined oil trading hub by expanding and upgrading its existing refineries.

[70] Ng, *Singapore, the Energy Economy*, 9.

[71] Ng, 12.

[72] Ng, 12.

[73] Ng, 12.

[74] Ng, 25.

[75] Ng, 25.

[76] Ng, 25.

Given Singapore's land constraints and small domestic market for oil, is it worth investing billions of dollars to build larger and more complex refineries? According to the consulting firm Purvin & Gertz, worldwide refineries are projected to cost US$205 billion to expand, upgrade, and maintain the facilities through 2015.[77] The firm expects this figure to decrease to US$110 billion through 2025. Ng attributes the forecasted slowdown in refining investments to poor margins, weakening demand from developing countries, rising energy conservation efforts, and the easy supply of cheap crude oil.[78] Moreover, Purvin & Gertz notes that the global increase in refining capacity and the slowing demand for refined oil has created a near-term oversupply, putting the weaker refineries at risk of shutting down.[79] The volatility in the oil refining industry therefore presents a risk not only to Singapore's economy but also to its long-term energy security.

To mitigate the risks to economic growth and increase the value of existing oil refineries, Singapore introduced petrochemical investments into the energy sector. In 2010 and 2012, Shell and ExxonMobil built petrochemical facilities on Jurong Island which allowed three of Singapore's oil refiners to serve as feedstock suppliers and less as fuel suppliers.[80] To date, Jurong Island has employed over 25,000 personnel, attracted the major operations of over 100 global chemical firms, and drawn fixed asset investments in excess of US$36 billion.[81]

From an energy security perspective, disruptions in foreign petroleum supply are mitigated by initiatives to increase Singapore's oil storage capacity. For example, the government invested US$758 million to develop the Jurong Rock Caverns, the first underground oil storage facility in Southeast Asia, capable of storing up to 9.2 million

[77] Purvin & Gertz, "Purvin & Gertz Releases Global Petroleum Market Outlook," accessed November 15, 2019, https://www.prnewswire.com/news-releases/purvin--gertz-releases-global-petroleum-market-outlook-88993467.html.

[78] Ng, *Singapore, the Energy Economy*, 27.

[79] Purvin & Gertz, "Purvin & Gertz Releases Global Petroleum Market Outlook."

[80] Ng, *Singapore, the Energy Economy*, 28.

[81] Singapore Economic Development Board, "Energy & Chemicals Industry in Singapore," accessed November 15, 2019, https://www.edb.gov.sg/en/our-industries/energy-and-chemicals.html.

barrels of liquid hydrocarbons.[82] Moreover, Singapore's other oil stockpiles are held by independent commercial terminals and private sector oil refiners, amounting to a total of 126 million barrels of oil, and translating to around 300 days of emergency supply.[83]

From an economic standpoint, Singapore's large storage facilities aid the development of the Asian "spot market," where a surplus of oil supply from the West arrives in Asia in search of new outlets.[84] Hong writes:

> The presence of a large number of independent storage facilities has not only attracted the oil majors to Singapore but also independent trading houses. Independent storage facilities meant large trading houses could trade like the oil majors. They could now move oil across from various other locations, store, blend, and trade these products into the different parts of Asia.[85]

Singapore's storage facilities also enable trading houses to capture the "contango."[86] In commodities trading, contango occurs when the future price of an asset is higher than the current spot price.[87] This concept allows trading houses to purchase relatively cheap oil, deposit in storage facilities, and sell to consuming centers for profit when spot prices increase.[88]

To further mitigate the risks to energy security while promoting environmental sustainability, Singapore started replacing oil with natural gas in the electricity generation sector, resulting in less carbon-intensive fossil fuels and representing as much as 95% of the country's current energy mix. The next section investigates Singapore's use of natural gas.

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[82] Mayuko Tani, "Singapore Burrows beneath Jurong Island for Oil Storage," Nikkei Asian Review, accessed November 20, 2019, https://asia.nikkei.com/Economy/Singapore-burrows-beneath-Jurong-Island-for-oil-storage.

[83] Tilak Doshi, *Singapore in a Post-Kyoto World: Energy, Environment and the Economy* (Singapore: Institute of Southeast Asian Studies, 2015), 181, http://ebookcentral.proquest.com/lib/ebook-nps/detail.action?docID=5124051.

[84] Hong, "Overview of Singapore's Energy Situation," 37.

[85] Hong, 37.

[86] Hong, 39.

[87] James Chen, "Futures and Commodities Trading: Contango," Investopedia, accessed December 2, 2019, https://www.investopedia.com/terms/c/contango.asp.

[88] Hong, "Overview of Singapore's Energy Situation," 39.

D. NATURAL GAS

The addition of natural gas to Singapore's energy landscape is a more recent development compared to the long and established history of petroleum. Natural gas was first introduced in 1992 by Senoko Energy, Singapore's largest power generation company, through pipelines running from Malaysia's state oil and gas company Petronas.[89] Senoko Energy's environmental and commercial success paved the way for the rapid growth phase of Singapore's natural gas industry, leading to more long-term contracts with the international market. In 2001, Singapore signed a US$9 billion contract with Indonesia to import piped natural gas (PNG) from Sumatra, marking the transition to a greener economy.[90]

The rapid incorporation and importance of natural gas in Singapore's energy landscape are evident when comparing Singapore's fuel mix to the rest of the world. Figure 4 shows that Singapore's energy industry by 2013 was much less carbon-intensive compared to other nations that still used coal for electricity generation. Regardless of the statistics, Doshi views Singapore's major transition to natural gas as long overdue because the world began turning away from oil in the 1970s as a result of the global oil price shocks.[91] Despite the belated action, Singapore has outpaced most countries in quitting the coal industry and investing in more sustainable sources of energy. One notable achievement is that Singapore's finance sector is moving away from funding coal-fired power plants in Asia, signaling that energy financing portfolios can contribute to meeting the country's pledges on climate change.[92]

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[89] Ng, *Singapore, the Energy Economy*, 131–33.

[90] Gas Supply Pte Ltd, "Pertamina and Singapore Power Sign Sales Agreement for Supply of Natural Gas to Singapore," accessed November 19, 2019, http://www.gassupply.com.sg/latest_news/the_news/2001/12_feb_2001.htm.

[91] Doshi, *Singapore in a Post-Kyoto World*, 182.

[92] Robert Hicks, "UOB Is Singapore's Third Bank to Quit Coal Power Lending in a Month," Eco-Business, accessed November 20, 2019, http://www.eco-business.com/news/uob-is-singapores-third-bank-to-quit-coal-power-lending-in-a-month/.

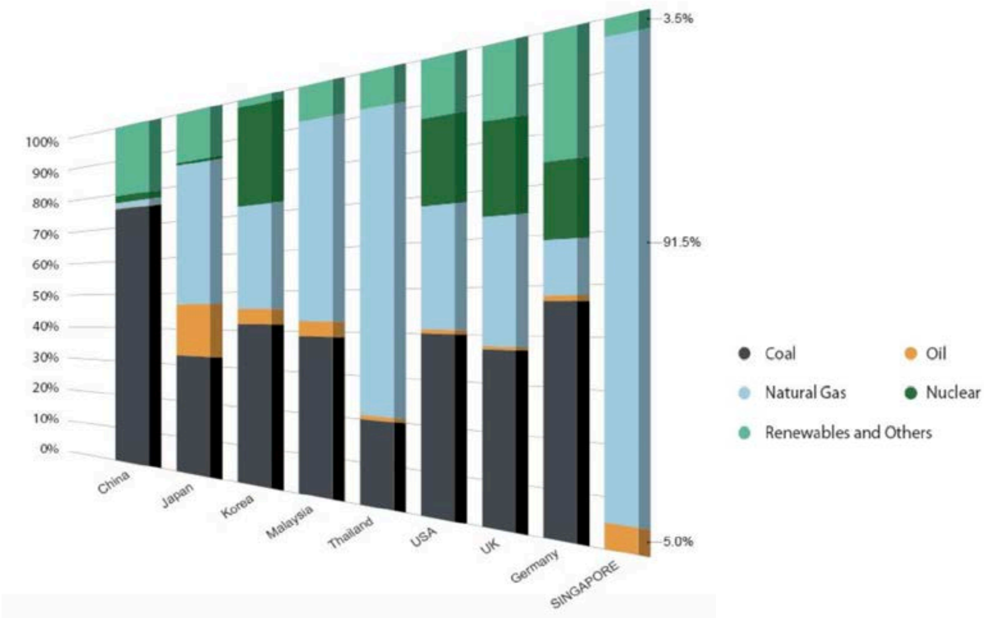

Figure 4. Fuel Mix for Power Generation by Country, 2013.[93]

The switch to natural gas as a fuel source was an easy choice to make. For most of the 1980s and 1990s, the residents of Singapore were subject to the harmful effects of burning oil for electricity generation.[94] Acid rain and air led to the corrosion of vehicles, in addition to the health and environmental consequences that became harder to ignore. Compared to petroleum, the burning of natural gas emits almost no particulates and little carbon monoxide and nitrogen oxide, making it a more favorable option for electricity generation.[95] In addition, Ng emphasizes that "while gas costs more than fuel oil on a calorific basis, it yields better economics because gas-fired combined-cycle plants are more efficient than oil-fired thermal plants."[96]

Despite the efficiency of natural gas for power generation, this energy source carries vulnerabilities in the long run. For example, in 2006, Singapore realized the

[93] Source: National Climate Change Secretariat Strategy Group Prime Minister's Office, "Power Generation," accessed April 11, 2020, https://www.nccs.gov.sg/singapores-climate-action/power-generation/.

[94] Ng, *Singapore, the Energy Economy*, 133.

[95] Ng, 133.

[96] Ng, 134.

unreliability of Indonesia and Malaysia as long-term natural gas suppliers.[97] Technological failures and geopolitical realities intervened, forcing Singapore to rethink its energy landscape. Between 2002 and 2004, Singapore experienced at least five power disruptions from the underwater pipeline system, causing businesses and residences to suffer significant losses.[98] The vulnerability of the piped gas infrastructure was also revealed when Indonesian separatist forces threatened to shut down Exxon-Mobil's gas production facilities in Sumatra.[99] Similarly, intelligence gathered after the September 11, 2001 bombing of the World Trade Center showed Al-Qaeda's plans to target Singapore's commercial and energy infrastructure.[100] Although the Al-Qaeda plot was never carried out, the threat emphasized the importance of resource diversification to ensure the continuity of energy supply.

Singapore's pipeline gas supply and contracts with Malaysia and Indonesia are summarized in Table 2. In evaluating the evolution and trajectory of Singapore's PNG industry, Doshi writes:

> The energy landscape in both Malaysia and Indonesia has changed since these contracts were signed. The lack of major discoveries and gas field developments has resulted in dwindling gas supplies relative to rapid domestic demand growth. Both countries have expressed concern over declining domestic gas production and their ability to meet rapidly growing domestic demand as well as servicing their export commitments…this caused considerable uncertainty over whether the existing contracts [with Singapore] would be renewed.[101]

Indeed, domestic consumers in Malaysia and Indonesia threaten Singapore's long-term PNG reserves. In 2006, President Susilo Bambang Yudhoyono of Indonesia announced a policy shift that limited Indonesia's export of gas in favor of its domestic customers.[102] As

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[97] Ng, *Singapore, the Energy Economy,* 133.

[98] Ng, 137.

[99] Michael Schuman and Thaddeus Herrick, "Exxon Mobil's Gas Shutdown in Aceh Shows Unrest's Cost," *Wall Street Journal*, April 4, 2001, https://www.wsj.com/articles/SB986332572505839907.

[100] CNN, "Tape Shows Singapore Attack Plans," January 12, 2002, https://www.cnn.com/2002/WORLD/asiapcf/southeast/01/12/ret.singapore.attack/index.html.

[101] Doshi, *Singapore in a Post-Kyoto World,* 183.

[102] Ng, *Singapore, the Energy Economy,* 142.

a result, Singapore was forced to diversify beyond piped gas supplies and chose to invest in the LNG industry to open the country to a variety of international sources beyond Asia.

Table 2. Singapore Pipeline Gas Supply and Contracts.[103]

Seller	Buyer	Pipeline	Start Year	End Year	Annual Contract Quantity (BSCM)
Pertamina (Indonesia)	Sembgas	West Natuna (Indonesia) – Singapore	2001	2022	3.37
Petronas (Malaysia)	Senoko	Peninsular Malaysia – Singapore	2001	2015	1.6
Petronas (Malaysia)	Keppel	Malaysia Plentong – Singapore	2005	2023	1.189
Pertamina (Indonesia)	Gas Supply	South Sumatra (Indonesia) – Singapore	2006	2023	3.65
Conoco (Indonesia)	Island Power	South Sumatra (Indonesia) – Singapore	2009	2023	1.04

In contrast to PNG, LNG is gas cooled to negative 260 degrees Fahrenheit to transform into the liquid state, reducing the normal gas volume by 600 times and allowing efficient transport over long distances through specially insulated tankers.[104] Once it reaches its final destination, LNG is warmed, re-gasified, and introduced to the gas network for distribution to end-users.

Whereas Singapore previously imported all its natural gas through Indonesian and Malaysian pipelines, the opening of the first LNG terminal on Jurong Island in 2013 has allowed Singapore to tap the global gas market, particularly the United States and Australia.[105] According to Singapore LNG Corporation chief executive John Ng, the terminal "now has enough capacity to meet the city-state's total gas demand, even if it were to stop importing natural gas through pipes."[106] Singapore's total natural gas demand in

[103] Source: Doshi, *Singapore in a Post-Kyoto World*, 183.

[104] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 30.

[105] Irving Low and Tim Rockell, "Commentary: The Future for Singapore's Energy Burns Bright," *Channel News Asia*, November 2, 2017, https://www.channelnewsasia.com/news/singapore/commentary-the-future-for-singapore-s-energy-burns-bright-9366042.

[106] Andrea Soh, "SLNG Terminal Has Enough Capacity to Replace Piped Gas If Necessary: CEO," *The Straits Times*, January 22, 2018, https://www.straitstimes.com/business/companies-markets/slng-terminal-has-enough-capacity-to-replace-piped-gas-if-necessary-ceo.

2018 was nine million tonnes, well under the LNG terminal's regasification capacity of 11 million tonnes.[107]

In the context of the energy trilemma, Singapore's venture into the LNG industry seems like a winner in three dimensions. First, the addition of alternative sources of energy enhances energy security by reducing supply risks and enabling the government to meet current and future demands. Second, LNG promotes environmental sustainability because of its lower carbon footprint compared to other fossil fuels such as coal and petroleum. Third, in conjunction with Singapore's liberalized electricity market, LNG enhances energy equity by making energy accessible and affordable across the population. Most of all, LNG advances Singapore's ultimate objective of economic growth because the LNG industry promises profitable opportunities beyond refined oil trading.

Singapore not only intends to meet its domestic energy needs but also to capitalize on the LNG infrastructure for industrial growth. Ng writes, "Singapore's planners believe it is in a strong position to become an international LNG trading center through the use of the import terminal, pipeline and shipping infrastructure, financial system and strategic position between consumers in Northeast and South Asia, and suppliers from the Middle East, Russia, and Australia."[108] For example, the terminal can be used for storage and trading of LNG as well as liquefied petroleum gas (LPG). It can also offer low-cost and low-carbon solutions for gas processing. Singapore is also exploring the feasibility of using LNG as bunker fuel for ships.[109]

Certainly, Singapore is poised for economic success as the forecast for the LNG market is promising. According to a study released by Research and Markets:

> The market for LNG in Singapore is projected to grow at a [compound annual growth rate] of 10.39% during 2016–2021. Increasing demand for LNG from end-users, declining LNG prices, strategic geographical location in Asia-Pacific, and implementation of favorable government policies are a

[107] Soh, "SLNG Terminal Has Enough Capacity to Replace Piped Gas If Necessary: CEO."

[108] Ng, *Singapore, the Energy Economy*, 150.

[109] Ng, 151.

few of the major factors expected to boost demand for LNG in Singapore."[110]

On the global scale, demand for LNG is expected to increase through 2040 particularly in Asia, as illustrated in Figure 5. As reported by S&P Global Platts Analytics, "75% of the world's LNG demand growth to 2040 will come from Asia, against only 30% of supply growth in the energy-hungry continent over a comparable period."[111] Given this backdrop, Singapore can leverage its LNG technology and experience in oil trading to become Asia's leading energy trading hub, helping Singapore pursue its ultimate ambition of sustained economic growth.

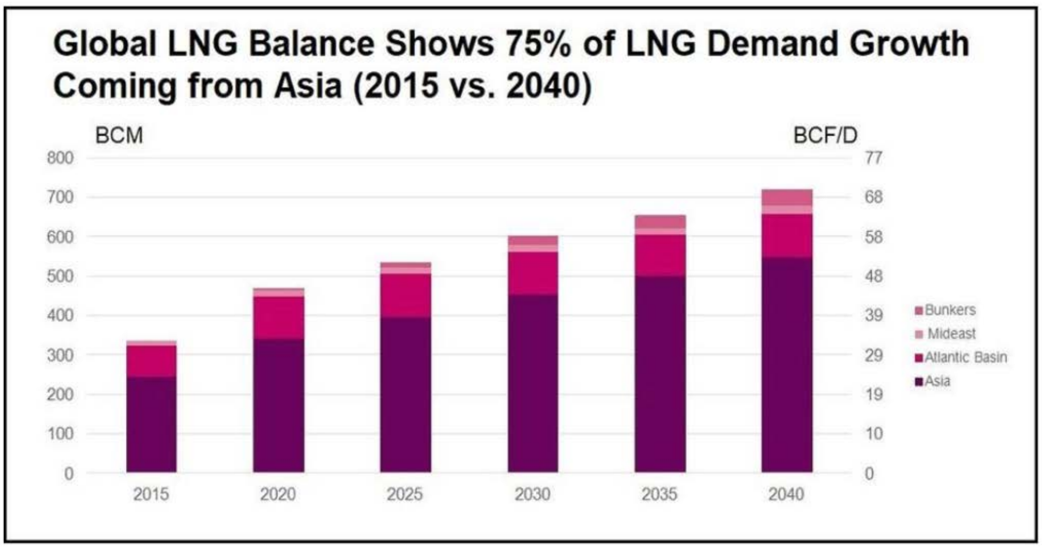

Figure 5. LNG Demand Forecast for Asia.[112]

[110] Business Wire, "Singapore LNG Market Demand & Supply Analysis, By Region, By Application, By LNG Terminal, Competition Forecast and Opportunities, 2011-2025 - Research and Markets," March 9, 2017, https://www.businesswire.com/news/home/20170309006208/en/Singapore-LNG-Market-Demand-Supply-Analysis-Region.

[111] Gaurav Sharma, "U.S. LNG Exporters Reshaping Global Natural Gas Markets," Forbes, March 7, 2018, https://www.forbes.com/sites/gauravsharma/2018/03/07/u-s-shale-exporters-reshaping-global-natural-gas-markets/.

[112] Source: Sharma, "U.S. LNG Exporters Reshaping Global Natural Gas Markets."

In reality, however, Singapore faces challenges as it drives toward LNG expansion. In the first place, issues of safety and security continue to haunt the Lion City, as it is located at the crossroads of the world's most crucial shipping lanes. Transport of LNG involves slow-moving marine tankers passing through the busy Strait of Malacca, increasing the risk of accidents and terrorist attacks.[113] Figure 6 illustrates the oil and LNG gas flows through the Strait of Malacca in a span of six years, reaching 16 million barrels per day.

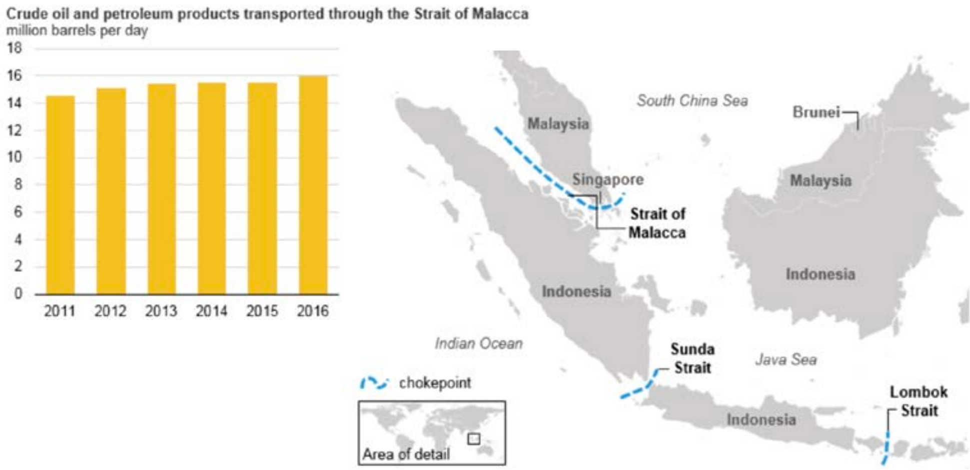

Figure 6. Oil and LNG Flows through the Strait of Malacca.[114]

In 2010, an oil tanker and bulk carrier collided in the Strait of Singapore, spilling 2,000 tonnes of crude oil into the sea.[115] Several other incidents have occurred resulting in oil spills despite Singapore's best efforts to manage maritime traffic along its coasts. In addition, Singapore received warnings of terrorist attacks on oil tankers transiting the

[113] Ng, *Singapore, the Energy Economy*, 147.

[114] Source: U.S. Energy Information Administration, "The Strait of Malacca, a Key Oil Trade Chokepoint, Links the Indian and Pacific Oceans," Today in Energy, August 11, 2017, https://www.eia.gov/todayinenergy/detail.php?id=32452.

[115] BBC News, "Oil Leaks from Singapore Tanker," May 25, 2010, sec. Asia-Pacific, https://www.bbc.com/news/10151722.

Malacca Strait, similar to the threats to the piped gas infrastructure.[116] Needless to say, the new stream of LNG tankers sailing through the primary chokepoint in Asia will require mariners with exceptional safety records complemented by tightened security measures of the Singapore Navy and Coast Guard.[117]

A second challenge pertains to the sustainability of natural gas as an energy source. Natural gas was initially referred to as a "bridge fuel," a fuel alternative that would help reduce GHG emissions until the world could totally rely on renewable energy sources.[118] But research shows that global temperatures will continue to rise even if natural gas were to dominate the electricity system. In one study, Howarth concludes that

> While it is true that less carbon dioxide is emitted per unit energy released when burning natural gas compared to coal or oil, natural gas is composed largely of methane, which itself is an extremely potent greenhouse gas. Methane is far more effective at trapping heat in the atmosphere than is carbon dioxide, and so even small rates of methane emission can have a large influence on the greenhouse gas footprints (GHGs) of natural gas use.[119]

Potential leaks exist in the natural gas production process, from ground extraction to land or sea transportation. While an individual leak is insignificant, the build-up of droplets amounts to a substantial methane concentration in the atmosphere, especially considering the network of pipelines and transport vessels involved in the operational chain.[120]

Third, there is the dilemma of oversupply, particularly influenced by the recent shale gas discoveries in Australia and the United States. Jaganathan reports, "The global LNG market is awash with new supply amid slowing demand in key countries such as

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[116] Neil Chatterjee, "Singapore Raises Security Alert after Malacca Threat," *Reuters*, March 5, 2010, https://www.reuters.com/article/us-malacca-threat-idUSTRE62335120100305.

[117] Ng, *Singapore, the Energy Economy*, 147.

[118] Robert W. Howarth, "A Bridge to Nowhere: Methane Emissions and the Greenhouse Gas Footprint of Natural Gas," *Energy Science & Engineering* 2, no. 2 (April 22, 2014): 47, https://doi.org/10.1002/ese3.35.

[119] Howarth, 47.

[120] Jordan Wilkerson, "Natural Gas Leaks Increase Climate Risk of Energy Source," *Science in the News* (blog), October 11, 2015, http://sitn.hms.harvard.edu/flash/2015/natural-gas-leaks-increase-climate-risk-of-energy-source/.

China and Japan, leaving some traders with cargoes they have bought but are unable to resell."[121] Energy companies are already seeing the effects of this trend. In November 2019, a Singapore-based gas importer absorbed sunk costs for canceling the loading of LNG cargo from the United States.[122] Natural gas is typically sold with "a liquefaction fee of between $3.00 to $3.50 per [millimeter British thermal units]," a price that traders still pay even if they decide to cancel purchases.[123] If the oversupply situation persists in the next few years, Singapore might be better off delaying plans for new LNG projects or expansion to await better market conditions.

Lastly, the biggest challenges for Singapore's LNG industry are low liquidity and storage.[124] According to S&P Global Platts,

> Low liquidity will continue to be the biggest challenge to Singapore's hub ambitions, as the limited size of its domestic gas market relative to the volume of LNG traded in Asia (which accounts for three quarters of global demand) makes it difficult for the country to replicate the balancing role the bigger and interconnected European hubs play in the global LNG markets. The prospects of its storage and reload initiative may also be limited by the inefficient nature of LNG re-exports. Unlike oil, the cost of transporting and handling LNG relative to its market price is significant.[125]

Natural gas storage in Singapore sells for US$2.5 million to US$6 million mmBtu per year, in addition to costs associated with reloading and re-export.[126] This suggests that storage expenses may be worth as much as the price of gas itself. In addition, natural evaporation or "boil-off" changes the quality and volume of gas over time, precluding the long-term

[121] Jessica Jaganathan, "Singapore Importer Cancels US LNG Cargo Loading," *Hart Energy News*, November 19, 2019, https://www.hartenergy.com/news/singapore-importer-cancels-us-lng-cargo-loading-184210.

[122] Jaganathan, "Singapore Importer Cancels US LNG Cargo Loading."

[123] Jaganathan, "Singapore Importer Cancels US LNG Cargo Loading."

[124] Abache Abreu, "Commentary: Singapore's Rising Natural Gas Ambitions Face Big Challenges," *Channel News Asia*, January 24, 2018, https://www.channelnewsasia.com/news/singapore/commentary-singapore-s-rising-natural-gas-ambitions-face-big-9871780.

[125] Abreu, "Commentary: Singapore's Rising Natural Gas Ambitions Face Big Challenges."

[126] Abreu, "Commentary: Singapore's Rising Natural Gas Ambitions Face Big Challenges."

storage of LNG.[127] Taken together, these factors contribute to the waning appetite for LNG reloads.

E. FINDINGS

Singapore's hydrocarbon industry vis-à-vis the energy trilemma is evaluated using a strengths, weaknesses, opportunities, and threats (SWOT) analysis. The analysis is then used to derive policy implications and to recommend avenues for improving future performance. The SWOT analysis of the hydrocarbon energy framework is as follows:

The strengths of the hydrocarbon industry are mainly the government's strategic involvement in national energy issues, the promotion of a competitive energy market, its status as an oil refining hub, and the country's switch to natural gas for electricity generation. Singapore should continue its whole-of-government approach to handle energy issues and maintain the competitive energy market to encourage prudent use of energy resources. Singapore should also use its expertise in oil trading and its skilled labor force to expand the natural gas industry, which could further secure its position as Asia's trading hub over regional competitors. Furthermore, Singapore is on the right track by replacing petroleum with natural gas for electricity generation. Natural gas enhances energy security by reducing supply disruptions and enabling the government to meet current and future energy demands.

The weaknesses in the hydrocarbon sector are mainly the lack of diversification away from fossil fuels resulting in high CO2 emissions, the weak climate target and absence of long-term goals related to hydrocarbon reduction, the low liquidity of LNG trading in Asia, and expensive cost of natural gas storage and transport. While most of these weaknesses are due to Singapore's geographical limitations and lack of indigenous resources, there are ways to mitigate the impact of these weaknesses. For example, Singapore's push for renewable sources of energy can increase the share of low-carbon non-fossil fuels in the energy mix. Nuclear energy can also reduce Singapore's carbon footprint and reduce dependence on foreign reserves. As for the lack of commitment to

[127] Dorde Dobrota, Branko Lalic, and Ivan Komar, "Problem of Boil-off in LNG Supply Chain," *Transactions on Maritime Science*, no. 2 (2013): 91–100, https://doi.org/10.7225/toms.v02.n02.001.

combatting climate change, Singapore can begin by revising its core energy policy documents and renewing its international pledges and targets to align national action with needed ambition.

With regard to opportunities, Singapore may take advantage of global developments such as the rise of international LNG trade to enhance its hydrocarbon industry. Singapore can leverage its LNG technology and experience in oil trading to become Asia's leading energy trading hub, helping Singapore pursue its ultimate ambition of sustained economic growth. The country's sizable capacity for oil storage also presents an opportunity for developing the Asian spot market by attracting oil majors and independent trading houses to establish trading operations in Singapore.

The threats that Singapore faces are the global increase in refined oil capacity and the decrease in the refined oil demand brought by shifting attitudes toward carbon-intense fuel sources. Likewise, there is the threat of oversupply of natural gas due to recent shale gas discoveries particularly in Australia and the United States. Moreover, natural gas infrastructures are vulnerable to terrorist attacks and foreign petroleum resources are subject to geopolitical conflict, social unrest, accidents in the Strait of Malacca, and natural disasters, all of which threaten Singapore's continuity of supply and stability of fuel prices.

These threats are largely beyond Singapore's control, but certain mitigation measures can forestall such developments. For instance, Singapore should delay plans for new LNG projects or expansion to await better market conditions. Singapore-based gas importers should also draft shorter-term contracts to match demand fluctuations, which will also minimize the sunk costs absorbed from canceling LNG cargo load-out overseas. In the case of foreign supply disruptions, Singapore must identify alternative suppliers in various geographical locations to mitigate the disruption from a certain region. As to threats to safety and security, more can be done to improve ship-handling and maritime safety. For example, Singapore can tighten the security measures of the Singapore Navy and Coast Guard, as well as encourage more regional cooperation to enhance the safety and freedom of navigation through Southeast Asia's most vital sea lanes.

III. NUCLEAR ENERGY

A. OVERVIEW

In an attempt to reconcile the three competing ends of the energy trilemma, many nations have turned to nuclear energy for carbon-saving commitments, reliability of energy supply, and competitive fuel pricing. At present, there are 451 nuclear power reactors in operation around the world, generating about 10.6% of the world's electricity supply.[128] In addition to this inventory, 58 nuclear power reactors are currently under construction worldwide, and 154 more are either on order or planned with funding and approvals.[129]

Nuclear energy does well in the clean energy spectrum because the fission of uranium atoms produces zero carbon emissions. The splitting process emits heat which is then used to create steam for turning turbines and generating electricity. The Nuclear Energy Institute in Washington, D.C., describes the power of a single uranium atom as, "one uranium fuel pellet creates as much energy as one ton of coal, 149 gallons of oil or 17,000 cubic feet of natural gas."[130] In terms of security of supply, nuclear energy does not depend on specific weather conditions or pipelines like other fuel sources.[131] In addition, nuclear energy works 24/7 and therefore does not require back-up power generation.[132]

In terms of pricing competitiveness, a combined study by the Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) concluded:

> At a 3% discount rate, nuclear is the lowest cost option for all countries. However, consistent with the fact that nuclear technologies are capital intensive relative to natural gas or coal, the cost of nuclear rises relatively

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[128] Mark Ho and John Harries, "Nuclear Can Solve the Energy Trilemma," *Energy Magazine*, September 5, 2018, https://www.energymagazine.com.au/nuclear-can-solve-the-energy-trilemma/.

[129] Ho and Harries, "Nuclear Can Solve the Energy Trilemma."

[130] Nuclear Energy Institute, "Fundamentals: Nuclear Fuel," Nuclear Energy Institute, accessed January 20, 2020, https://www.nei.org/fundamentals/nuclear-fuel.

[131] Nuclear Energy Institute, "Advantages: Infrastructure," Nuclear Energy Institute, accessed January 20, 2020, https://www.nei.org/advantages/infrastructure.

[132] Ho and Harries, "Nuclear Can Solve the Energy Trilemma."

> quickly as the discount rate is raised. As a result, at a 7% discount rate the median value of nuclear is close to the median value for coal, and at a 10% discount rate the median value for nuclear is higher than that of either CCGTs or coal.[133]

To clarify, a 3% discount rate accounts for the "social cost of capital"; a 7% discount rate accounts for rates in restructured or de-regulated electricity markets; and a 10% discount rate accounts for investments in high-risk environments.[134] As shown above, at lower discount rates, energy generated by nuclear power plants is the cheapest option for consumers.

Given the benefits of nuclear energy and its solutions to the energy trilemma, why has Singapore not adopted nuclear technology in its energy landscape? Are there plans to incorporate nuclear power in the resource-constrained country? This chapter examines the four major issues concerning nuclear energy in Singapore: (1) economic, (2) environmental, (3) social, and (4) political. As in the previous chapter on hydrocarbons, this chapter concludes with a SWOT analysis of the nuclear energy sector to derive policy implications and offers recommendations toward Singapore's nuclear future.

B. AMBITIONS

In an era of fluctuating oil prices and global climate change, nuclear energy has recently become a popular idea in Singapore's energy industry. Although Singapore today has no nuclear power program, the government's stand on the use of nuclear technology has shifted over the years. In 2007, the same year the first national energy policy was published, Prime Minister Lee Hsien Loong ruled out nuclear energy because land scarcity precluded Singapore from establishing the necessary 30 km safety radius around nuclear power plants.[135]

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[133] OECD Nuclear Energy Agency and International Energy Agency, "Projected Costs of Generating Electricity 2015 Edition," September 30, 2015, 14, https://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf.

[134] OECD Nuclear Energy Agency and International Energy Agency, 27–28.

[135] Samantha Boh, "Will Singapore Warm up to Nuclear Energy to Beat Climate Change," *South China Morning Post*, July 22, 2019, https://www.scmp.com/week-asia/economics/article/3019393/will-singapore-warm-nuclear-energy-combat-climate-change.

Three years later, the government conducted a pre-feasibility study on nuclear energy, signaling an effort to explore other avenues for overcoming the country's energy constraints and enhance energy security.[136] The study determined that "nuclear energy technologies presently available are not suitable for deployment in Singapore," and that Singapore preferred to wait for "safer and more robust designs" before reconsidering its options.[137] Interest in nuclear energy further waned after the 2011 Fukushima nuclear disaster in Japan, which triggered a global rethink of uranium fission as an energy source.[138]

Singapore recognizes the need to understand nuclear science and technology despite the absence of concrete plans to build nuclear reactors. In 2013, Singapore approved a SGD$63 million fund to develop the Nuclear Safety Research and Education Program (NSREP).[139] The program aims to build Singapore's credibility in nuclear technology, conduct research, and evaluate the implications of emerging nuclear trends both regionally and globally.

One component of the NSREP is the Singapore Nuclear Research and Safety Initiative (SNRSI), which aims to "concentrate expertise and knowledge in nuclear technology and safety in a single institute, and sustain a critical mass of manpower engaged in a range of nuclear-related activities relevant to Singapore."[140] To meet this goal, the SNRSI developed a three-fold strategy: (1) to recruit, educate, and establish a core of nuclear scientists and experts through programs in local and international universities; (2) to maintain nuclear research laboratories capable of providing technical support; and (3) to engage in regional and global cooperation to improve nuclear safety. By focusing on building technical capacity and expanding the knowledge base, Singapore is on track toward becoming a rational player in Southeast Asia's nuclear future.

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[136] Ministry of Trade and Industry, "Factsheet Nuclear Energy Pre-Feasibility Study," 1.

[137] Ministry of Trade and Industry, 1.

[138] Boh, "Will Singapore Warm up to Nuclear Energy to Beat Climate Change?"

[139] National University of Singapore, "Singapore Nuclear Research and Safety Initiative," accessed January 20, 2020, http://snrsi.nus.edu.sg/about-us/about.html.

[140] National University of Singapore, "Singapore Nuclear Research and Safety Initiative."

C. ECONOMIC FACTORS

For a country where economic growth has historically taken center stage, the adoption of a new energy sub-sector requires extensive cost-benefit analysis to ensure economic progress is not compromised. The Singapore government has not conducted such an analysis, although a study conducted by the National University of Singapore (NUS) in 2014 reveals:

> The levelized cost of electricity from recently built nuclear power plants in Japan and the Republic of Korea is 8.4 ¢/kWh, denominated in 2007 dollars, which is more cost effective compared to 2007 Singapore electricity tariff of 20.2 ¢/kWh. As both countries are comparable to Singapore in terms of labor, operation cost and technology advancement…it is cheaper to substitute oil and gas power generation [with] nuclear power.[141]

This statement echoes the results published by the NEA and the IAEA on the projected costs of electricity generation as mentioned early in this chapter—that energy generated by nuclear power plants (not accounting for discount rates) is the cheapest option for consumers.

It is important to note that both studies published by the NUS and the NEA-IAEA collaboration utilized the levelized cost of energy (LCOE) methodology. The LCOE accounts for the operation cycle and expected lifetimes of power plants, amortized over an assumed financial lifetime.[142] But the two reports also recognize that the LCOE does not accurately reflect the true cost of nuclear power generation. The NUS study claims that additional costs incurred from the construction phase of nuclear power plants are often transferred to consumers in the form of increased electricity prices.[143] The NEA-IAEA study adds, "the LCOE should be accompanied by other metrics when choosing among

[141] Eng Seng Chia et al., "The System Dynamics of Nuclear Energy in Singapore," *International Journal of Green Energy* 12 (September 16, 2014): 3, https://doi.org/10.1080/15435075.2014.889001.

[142] U.S. Energy Information Administration, "Power Plants' Costs and Value to the Grid Are Not Easily Reflected Using Simple Metrics," May 3, 2017, https://www.eia.gov/todayinenergy/detail.php?id=31052.

[143] Chia et al., "The System Dynamics of Nuclear Energy in Singapore," 4.

electricity generation technologies."[144] This is because the LCOE methodology was based on regulated markets when, in reality, electricity markets may diverge from this origin.

The U.S. Energy Information Administration (EIA) cautions against using simple metrics such as the LCOE for comparing costs across various technologies and fuels.[145] According to the EIA:

> Because LCOEs do not include contractual terms on price, duration, or price inflators, they should not be directly compared with other prices such as power purchase agreements. Power purchase agreements may involve project- or corporate-specific finance terms, reflect differing contract terms with the power purchaser, or reflect the value rather than the cost of the energy.[146]

In addition, the LCOE methodology may not capture tax incentives and the effect of state or local programs, and it overlooks the differences in the operation of generating technologies.[147] For example, some plants operate around the clock, while others only run during peak hours. Some power plants depend on wind and solar energy to operate, energy which may not be available continuously.[148] Singapore must keep these caveats in mind when conducting its cost-benefit analysis of nuclear energy in the future.

Another economic factor for consideration pertains to the carbon tax. In 2019, Singapore implemented the Carbon Pricing Act which imposes a SGD$5 carbon tax for every tonne of GHG emissions on industrial facilities, including power generating companies.[149] This means that direct emitters will have to either cut down on fossil fuel consumption or become more energy efficient to avoid additional costs incurred from

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[144] OECD Nuclear Energy Agency and International Energy Agency, "Projected Costs of Generating Electricity 2015 Edition," 27.

[145] U.S. Energy Information Administration, "Power Plants' Costs and Value to the Grid Are Not Easily Reflected Using Simple Metrics."

[146] U.S. Energy Information Administration, "Power Plants' Costs and Value to the Grid Are Not Easily Reflected Using Simple Metrics."

[147] U.S. Energy Information Administration, "Power Plants' Costs and Value to the Grid Are Not Easily Reflected Using Simple Metrics."

[148] U.S. Energy Information Administration, "Power Plants' Costs and Value to the Grid Are Not Easily Reflected Using Simple Metrics."

[149] National Environment Agency of Singapore, "Carbon Tax," accessed January 25, 2020, https://www.nea.gov.sg/our-services/climate-change-energy-efficiency/climate-change/carbon-tax.

carbon emissions. That the carbon tax increased the cost of electricity generated from coal, petroleum, and natural gas is one reason for nuclear energy to be added to Singapore's arsenal.

Lastly, the nuclear energy industry can stimulate Singapore's economy. As an engine for job creation, the industry can create a "total lifetime employment [of] 200,000 labour-years, or about 400 million labour-hours" for every "1,000MWe (net) advanced light water unit" and the statistics are expected to grow with increasing electricity demand.[150] Another energy agency adds, "a single nuclear power plant creates more jobs than any other type of energy generation facility."[151] The nuclear energy industry employs workers from a wide range of expertise and educational backgrounds—from administrative, to operation and maintenance, to construction and supply chain, which can greatly enhance Singapore's employment prospects. Similarly, Singapore may trade with its neighbors any excess energy from nuclear power plants for additional revenue. In sum, Singapore could witness a growth of its labor force and enjoy economic dividends should it adopt nuclear energy in its future energy mix.

D. ENVIRONMENTAL FACTORS

One of the major appeals of nuclear energy is the perception that it is a clean source of energy. But this notion is misleading because studies have proven that nuclear energy releases carbon dioxide through "life cycle emissions."[152] These GHG emissions are products of the different phases of plant operation, such as construction, uranium mining and processing, and decommissioning. Figure 7 shows a comparison of the life cycle emissions of various sources of energy. While nuclear energy is shown as releasing 28 tonnes CO2e/GWh, it is among the lowest of any electricity generation method, making it a better option compared to the carbon-intense sources of energy.

[150] OECD Nuclear Energy Agency and International Atomic Energy Agency, "Measuring Employment Generated by the Nuclear Power Sector," 2018, 12, https://www.oecd-nea.org/ndd/pubs/2018/7204-employment-nps.pdf.

[151] Nuclear Energy Institute, "Jobs," accessed January 25, 2020, https://www.nei.org/advantages/jobs.

[152] Benjamin K. Sovacool, "Valuing the Greenhouse Gas Emissions from Nuclear Power: A Critical Survey," *Energy Policy* 36, no. 8 (August 1, 2008): 2950, https://doi.org/10.1016/j.enpol.2008.04.017.

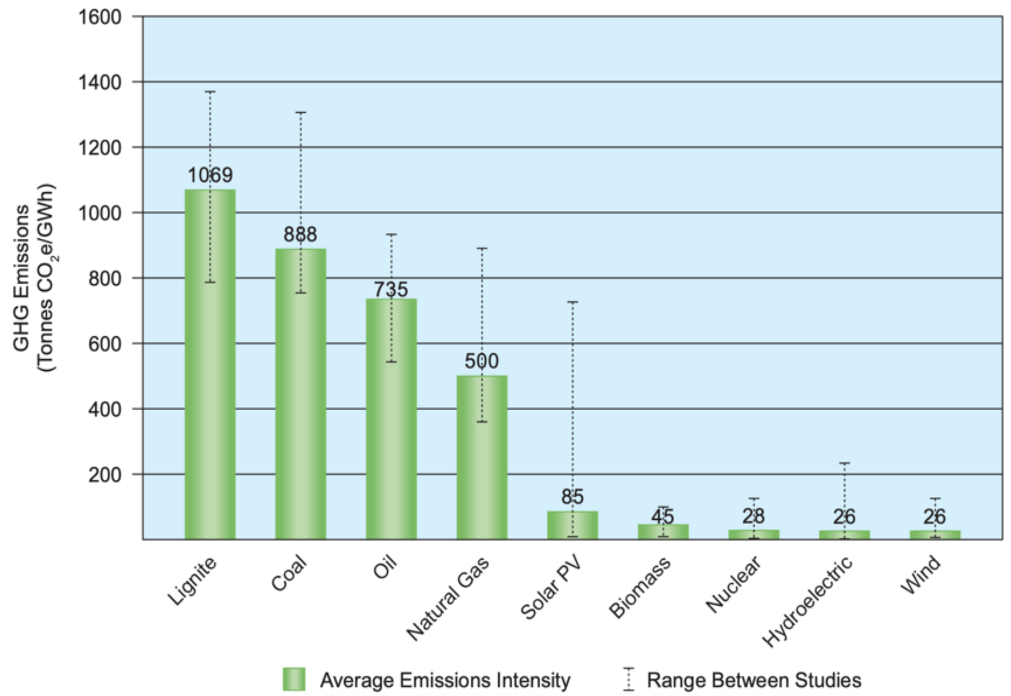

Figure 7. Life Cycle GHG Emissions Intensity of Various Electricity Generation Methods.[153]

A second environmental concern regarding nuclear energy is that low levels of radiation are constantly being emitted to the atmosphere by operating power plants. Studies from the United Kingdom, Germany, France, and Switzerland have shown an increased risk of leukemia in children living in the vicinity of nuclear installations.[154] Other diseases attributed to low-level radiation include thyroid and breast cancer, cardiovascular diseases, cataracts, perinatal mortality, and congenital defects.[155] On the other hand, the effects of low-level radiation on plants and wildlife are widely debated. Some suggest that animal

[153] Source: World Nuclear Association, "Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources" (London, United Kingdom, July 2011), 7, http://www.world-nuclear.org/uploadedFiles/org/WNA/Publications/Working_Group_Reports/comparison_of_lifecycle.pdf.

[154] Gabriele Mraz and Oda Becker, "Health Effects of Ionising Radiation and Their Consideration in Radiation Protection" (Vienna, Austria: Wiener Umweltanwaltschaft/Vienna Ombuds-Office for Environmental Protection, 2017), 3, http://www.joint-project.org/upload/file/Health_effects_and_radiation_protection_summary_2017.pdf.

[155] Mraz and Becker, 3–4.

and plant populations are unharmed at dose rates below 1 milligray per day.[156] Others report significant impacts on wildlife from low-level dose rates.[157] The lack of scientific consensus demands additional research on this topic to support future feasibility studies of nuclear energy industries.

Finally, waste management is a huge concern for the industry because waste from nuclear power plants can have residual radioactivity that may last for hundreds of years. Each stage in the fuel cycle generates radioactive waste—from mining of raw materials, to uranium ore processing, to assembly of fuel rods, and treatment of the spent fuel from the reactor.[158] Used fuel may be reprocessed to extract remaining uranium, a process that reduces the volume of high-level nuclear waste by about 85%.[159] Unprocessed fuel and contaminated steel components are either recycled within the industry or buried underground to minimize the impact on the environment. Referred to as "geological disposal," this process involves packaging the nuclear waste inside engineered barriers and storing the containers inside a rock volume underground to prevent radioactivity from reaching the surface and to allow natural radioactive decay.[160]

Singapore's geographic restrictions have prompted concerns as to whether it can handle the amount of nuclear waste.[161] But Palmer et al. argue that radioactive waste storage should not be a burden to Singapore, citing that the British nuclear power program generated high-level nuclear waste equivalent to only "one standard-size basketball court

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[156] International Atomic Energy Agency, "Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards," Technical Report Series (Vienna, Austria, 1992), 54, https://inis.iaea.org/collection/NCLCollectionStore/_Public/23/039/23039160.pdf; Nicholas A. Beresford and David Copplestone, "Effects of Ionizing Radiation on Wildlife: What Knowledge Have We Gained between the Chernobyl and Fukushima Accidents?," *Integrated Environmental Assessment and Management* 7, no. 3 (2011): 371, https://doi.org/10.1002/ieam.238.

[157] Beresford and Copplestone, "Effects of Ionizing Radiation on Wildlife," 371.

[158] World Nuclear Association, "Radioactive Waste Management," April 2018, https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx.

[159] World Nuclear Association, "Radioactive Waste Management."

[160] Government of the United Kingdom, "Geological Disposal of Radioactive Waste: A Guide for Communities," accessed January 29, 2020, https://www.gov.uk/guidance/managing-radioactive-waste-safely-a-guide-for-communities.

[161] Chia et al., "The System Dynamics of Nuclear Energy in Singapore," 21.

to just below the baskets" in its 50 years of operating 41 nuclear power plants.[162] A small nation-state like Singapore will not require 41 nuclear power plants to provide electricity to its population, which means any waste generated will be within manageable levels.

E. SOCIAL FACTORS

From a social perspective, there is general opposition to nuclear energy in Singapore due to the risk of nuclear accidents. Most of these fears are borne out of the Chernobyl and Fukushima incidents, as many Singaporeans expressed concern that accidents still occur despite established safety precautions.[163] Another misgiving pertains to threats of sabotage and the weaponization of nuclear energy. Some Singaporeans were concerned about the risks of nuclear terrorism and many believed that nuclear energy can be exploited and turned into weapons of mass destruction.[164]

Despite the lack of public support toward nuclear energy, some Singaporeans reluctantly accept the technology under the premise of commercial benefits, survival should Singapore deplete its traditional energy sources, and the perception that ordinary citizens do not possess the ability to oppose the government's decisions.[165] Among the many concerns, some experts wonder how the public's conditional acceptance of nuclear energy can transform into genuine approval. Ho et al. describe that "negative sentiments toward nuclear energy were attributed to the lack of nuclear-related expertise and technological capabilities to ensure nuclear safety currently…their support for nuclear energy were largely contingent on Singapore's nuclear-related capabilities."[166] Given these reasons, Singapore's policymakers can begin with educating the public and addressing myths surrounding nuclear energy. The establishment of the SNRSI as Singapore's official nuclear institution is a step in the right direction. The SNRSI's

[162] Palmer, Ramakrishna, and Cheema, "Nuclear Power in Singapore," 67.

[163] Shirley S. Ho et al., "'I Can Live with Nuclear Energy If…': Exploring Public Perceptions of Nuclear Energy in Singapore," *Energy Policy* 120 (September 1, 2018): 443, https://doi.org/10.1016/j.enpol.2018.05.060.

[164] Ho et al., 443.

[165] Ho et al., 444.

[166] Ho et al., 444.

authority, trustworthiness, and expertise in nuclear energy will help convey factual information, dispel misconceptions and allay public concerns, thus setting the scene for Singapore's future nuclear energy industry.

F. POLITICAL FACTORS

None of the countries in Southeast Asia currently has an operating nuclear power plant, although notable progress has been made in terms of program development in Vietnam, Indonesia, and Malaysia.[167] While a country's technical, financial, and institutional capacities play a significant role in the advancement of nuclear energy programs, regional relationships also factor into the success of such projects. Regional cooperation is necessary for the following reasons: (1) a nuclear contamination knows no borders; (2) a single nuclear accident can easily disrupt the region's fastest-growing economies; (3) the region's vital sea lanes are not tightly guarded by maritime security forces, risking the safe transport of radioactive materials.[168] It is therefore in the region's interest to collectively ensure nuclear security, safety and standards.

In 2018, the Association of Southeast Asian Nations (ASEAN) released an official report on the establishment of nuclear power plants in the region for the medium- to long-term period.[169] The report calculates that the first civilian-operated nuclear reactor in the region could be ready by 2030. Although regional conditions still need to be in place for the realization of the endeavor, Putra and Andrews-Speed claim, "the report itself is an indication that the ASEAN member states are working together and are open and transparent about their aspirations and state of nuclear power infrastructure development, which augurs well for the region."[170]

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[167] Nur Azha Putra, "The Dynamics of Nuclear Energy among ASEAN Member States," *Energy Procedia* 143 (2017): 585.

[168] Mely Caballero-Anthony et al., "The Sustainability of Nuclear Energy in Southeast Asia: Opportunities and Challenges" (Rajaratnam School of International Studies, October 2014), i, https://www.rsis.edu.sg/wp-content/uploads/2014/10/NTS-Report-October-2014.pdf.

[169] Nur Azha Putra and Philip Andrews-Speed, "Prospects for Nuclear Power in ASEAN," June 28, 2018, https://thediplomat.com/2018/06/prospects-for-nuclear-power-in-asean/.

[170] Putra and Andrews-Speed, "Prospects for Nuclear Power in ASEAN."

The report identifies Indonesia, Malaysia, Vietnam, Thailand and the Philippines as the frontrunners in the region's nuclear energy industry due to their "more advanced legal and regulatory frameworks, nuclear energy infrastructures, and developed organization and human resources."[171] In contrast, Singapore's commitment to nuclear energy has been limited to the development of its knowledge base in the areas of nuclear safety and science. However, Singapore has the potential to assume a leadership role in the nuclear energy subsector, given its affluent economy and strategic location in the Strait of Malacca. In particular, Singapore can take the lead in improving the maritime security of the region's most vital sea lanes to prevent illicit trafficking, sabotage, and an inadvertent movement of radioactive and fissile materials.

G. FINDINGS

Singapore does not have firm projections for when it will start building nuclear power facilities, but it is not ruling out nuclear energy in its future energy landscape. The strengths of Singapore's nuclear energy initiatives are mainly the government's allocation of significant resources through the NSREP to develop the country's nuclear knowledge base; the establishment of the SNRSI as Singapore's official institution to take the lead in nuclear-related matters and convey factual information to the public; and the implementation of the carbon tax that makes nuclear energy a more economically viable option. Singapore is also not expected to generate an unmanageable level of nuclear waste which eases the country's land scarcity dilemma.

As to weaknesses, the main critique is that the public has been hesitant in welcoming nuclear energy development. Ideally, public acceptance of national policies is necessary for a strategy to succeed; however, Singapore's style of democracy seems to discourage progress in this arena. Thus, progress toward social acceptance of nuclear power is contingent on whether Singapore can effectively educate and engage its citizens—an opportunity best reserved for the SNRSI, the organization which ultimately possesses the nuclear credibility to allay the concerns of the people. The lack of a cost-benefit analysis

[171] Putra and Andrews-Speed, "Prospects for Nuclear Power in ASEAN."

beyond the LCOE methodology is another weakness for Singapore and is therefore a great starting point for pushing nuclear development.

Other opportunities in Singapore's nuclear energy initiatives include the potential growth of its labor force and the possible economic dividends should the country decide to export its surplus nuclear energy to the regional electrical grid. The nuclear energy sector could also provide a venue for regional cooperation, beginning with Singapore taking the leading role in improving maritime security in Southeast Asia's most vital sea lanes. The nuclear energy industry demands a secure maritime environment to prevent illicit trafficking, sabotage, and the inadvertent movement of radioactive and fissile materials, and Singapore can influence regional safety given its strategic location in the Strait of Malacca.

Singapore faces the same threats as any other nation with a nuclear power program. These threats include low-level radiation exposure, risk of nuclear accidents, and nuclear terrorism and weaponization. As with the chapter on hydrocarbons, certain mitigation measures can forestall such incidents. For example, Singapore can reduce the population's exposure to low-level radiation by building nuclear reactors that adhere to the safety radius established by the IAEA. Given the country's land constraints, feasible locations include an underground nuclear power station or a floating platform out to sea.[172] Nuclear accidents can be mitigated through robust designs, containment, continuous training, regulatory oversight, periodic safety assessments, and a myriad of other ways dictated by international nuclear organizations. Regarding the threat of terrorism and weaponization of nuclear energy, Singapore should lead by improving the maritime security in the region, as discussed above.

The next chapter discusses the renewable energy subsector, which has seen a growing contribution to Singapore's energy landscape. Unlike nuclear energy still in the research and development phase, Singapore has adopted renewable energy from solar photovoltaics and biofuels. The government is taking advantage of more renewable energy

[172] Palmer, Ramakrishna, and Cheema, "Nuclear Power in Singapore," 68; Yew Seng Alvin Toh and Andrew Palmer, "Floating Nuclear Power for Singapore," *The IES Journal Part A: Civil & Structural Engineering* 7, no. 2 (April 3, 2014): 121, https://doi.org/10.1080/19373260.2014.886986.

options as it manages the three competing ends of the energy trilemma, while keeping in mind the intermittency challenges posed by these energy sources.

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IV. RENEWABLE ENERGY

A. OVERVIEW

Renewable energy refers to energy that is obtained from inexhaustible resources such as biofuels, hydropower, geothermal, wind, and solar.[173] Until the beginning of the 21st century, renewable sources of energy had only been the advocacy of environmental groups. Today, interest in the renewable energy sector has expanded to governments, businesses, and consumers, owing in part to the universal consciousness brought by climate change, resource scarcity, and rising energy prices.[174] In addition, advancements in technology have contributed to the global acceptance of renewables. Renewables have become much more financially viable from production to deployment, owing to research and development (R&D) activities sponsored by various government and corporate partnerships worldwide.[175]

The main appeal of renewable energy is in its environmental benefits, particularly the absence of greenhouse gas (GHG) emissions from these fuel sources. However, Quek et al. contend that "while renewable energy systems are less pollutive in general than fossil fuels at their point of use, environmental impacts can be high at other stages in the life cycle of the system."[176] They conclude, "switching to renewable energy sources does not necessarily reduce environmental impacts…each energy source requires a unique mix of resource inputs and uses a different technology, which damages the environment in a different way."[177] This statement mirrors the life cycle emissions graph presented in Figure 7 of Chapter III. No form of energy is truly "clean" because GHGs are emitted at different phases of plant operation.

[173] U.S. Energy Information Administration, "Renewable Energy Explained," accessed February 10, 2020, https://www.eia.gov/energyexplained/renewable-sources/.

[174] Ng, *Singapore, the Energy Economy*, 179.

[175] Ng, 179.

[176] Augustine Quek et al., "Challenges in Environmental Sustainability of Renewable Energy Options in Singapore," *Energy Policy* 122 (November 1, 2018): 388, https://doi.org/10.1016/j.enpol.2018.07.055.

[177] Quek et al., 393.

Considering the impact of life cycle emissions, increasing the use of renewable energy in Singapore thus seems to achieve little in terms of environmental sustainability. But in terms of energy security and energy equity, the renewable energy industry is an effective way to manage the energy trilemma. On one hand, renewables enhance energy security by promoting fuel diversification, reducing supply risks, and enabling the government to meet current and future energy demands. On the other hand, renewables improve energy equity by making energy accessible and affordable across the population. Most of all, the renewable energy industry promises economic growth through increased foreign investments and job opportunities. These facts are further discussed in this chapter.

Singapore's renewable energy options are limited to solar, biomass, and biogas due to its geographic constraints. The government identifies these limitations as follows: (1) average wind speed in Singapore is 2 meters per second (m/s), making commercial wind turbines which operate at 4.5 m/s an infeasible option; (2) tidal power generation is limited due to the country's narrow tidal range, calm seas, and the use of sea space for ports and shipping lanes; (3) Singapore does not have a fast-flowing river system which could harness hydroelectric power; and (4) Singapore does not have geothermal energy sources.[178] Therefore, this chapter excludes a discussion on hydropower, geothermal, and wind energy due to their zero potential contribution to meeting Singapore's energy demands.

Singapore is not, however, without viable renewable energy options. Solar energy is power generated by the sun that is converted into thermal or electrical energy. One way to harness solar energy is through photovoltaic (PV) devices that are semiconductors found in solar panels that convert photons into electrical current.[179] Located near the equator, Singapore receives annual solar irradiation of 1,500 kilowatt-hours per square meter, which makes solar PV a viable renewable energy option.[180]

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[178] National Climate Change Secretariat, "Singapore's Approach to Alternative Energy."

[179] Solar Energy Industries Association, "Photovoltaics," accessed February 11, 2020, https://www.seia.org/initiatives/photovoltaics.

[180] National Climate Change Secretariat, "Singapore's Approach to Alternative Energy."

Similarly, biomass and biogas—both derived from living matter—are options available for consideration. Singapore's biomass component includes wood waste, agricultural waste, food waste, and paper, all of which are sent to waste-to-energy (WTE) plants or cogeneration plants for incineration to produce energy.[181] Similarly, biogas is derived from organic material, but these waste products undergo anaerobic digestion, a biological mechanism involving the decomposition of organic material without the use of oxygen.[182] This decomposition produces methane and carbon dioxide, which is then converted into heat and electricity. Although Singapore's renewable energy options are limited, innovations in the solar, biomass, and biogas industries seem promising in responding to the country's energy demands.

B. AMBITIONS

Singapore's venture into renewable energy began in April 2006 after it acceded to the Kyoto Protocol, a treaty that aimed to reduce GHG emissions from industrialized nations.[183] As part of its renewable energy plan, the Ministry of Trade and Industry (MTI) recommended that renewable energy should supply 5% of Singapore's peak electricity demand by 2020.[184] In 2019, Singapore's peak demand was 7,217 MWp.[185] This means that around 360 MWp must be supplied by renewable energy sources to meet the MTI's goals.

The National Climate Change Secretariat (NCCS), the agency in charge of coordinating Singapore's domestic and international policies related to climate change, turned the MTI's recommendation into concrete goals by aiming to provide 350 MWp of electricity to consumers using solar PV by 2020.[186] By the end of the second quarter of

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[181] Ng, *Singapore, the Energy Economy*, 189.

[182] Eco Sustainable Solutions, "The Difference Between Biomass and Biogas," accessed February 11, 2020, https://www.thisiseco.co.uk/news_and_blog/the-difference-between-biomass-and-biogas.html.

[183] Ng, *Singapore, the Energy Economy*, 180.

[184] Jen and Iswaran, "ESC Subcommittee on Ensuring Energy Resilience and Sustainable Growth," 87.

[185] Energy Market Authority of Singapore, "Monthly Peak System Demand," accessed February 11, 2020, https://www.ema.gov.sg/statistic.aspx?sta_sid=201408047htU7faVzLaZ.

[186] National Climate Change Secretariat, "Singapore's Approach to Alternative Energy."

2019, Singapore's grid-connected solar capacity was at 262.4 MWp.[187] Figure 8 shows a sharp increase in solar capacity from 2012 to 2019, indicating that the government is on track to meet its 2020 target. Consequently, the NCCS foresees that by 2030, up to 8% of electricity requirements could be supplied by renewable energy given the country's R&D capabilities and an influx of foreign investments.

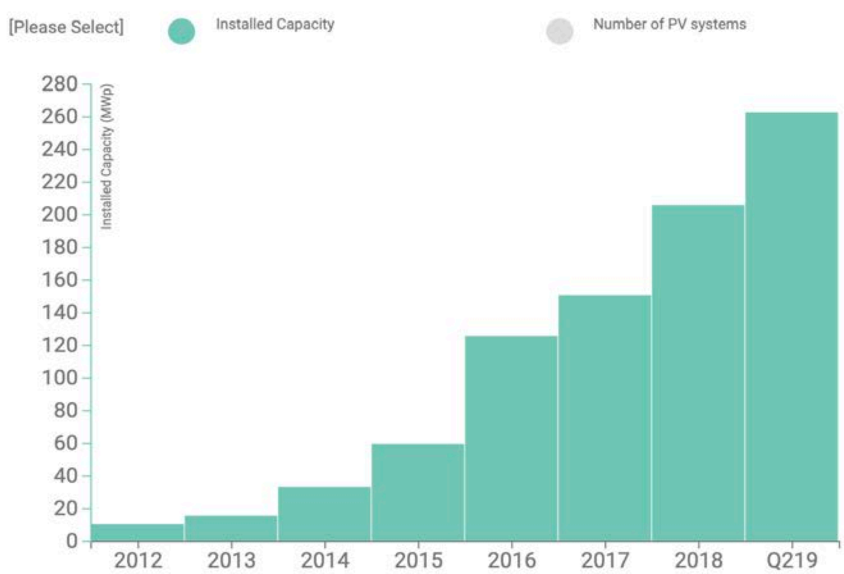

Figure 8. Installed Capacity of Solar Photovoltaic Systems, 2012–2019.[188]

Singapore's biofuels industry is less established than its solar counterpart. Although the MTI announced a proposal in 2007 to integrate biofuels into Singapore's energy landscape, Ng believes that the plan collapsed due to "rising feedstock cost, poor economics, uncertain demand outlook, and controversy over the ethics of using food crops for fuel production and its role in the destruction of rainforests in Indonesia and Malaysia."[189] Specifically, Ng points out that the ethics of using food crops to generate

[187] Energy Market Authority, "2019 Singapore Energy Statistics - Solar," accessed February 11, 2020, https://www.ema.gov.sg/Singapore-Energy-Statistics-2019/Ch06/index6.

[188] Source: Energy Market Authority, "2019 Singapore Energy Statistics - Solar."

[189] Ng, *Singapore, the Energy Economy*, 187.

fuel became controversial when food and grain prices inflated from 2007 to 2008, harming low-income families around the world. Furthermore, the energy industry could not predict when biofuels would become profitable. For instance, Neste Oil could not give a timeline on when its biodiesel sales volumes would increase significantly, and instead the company ran into financial difficulty when the prices of palm oil-based biodiesel tripled in 2008.[190]

Despite the failure to fully integrate biofuels in Singapore's energy landscape, the country currently has four operational WTE plants capable of processing 8,200 tonnes of solid waste per day.[191] The heat from incineration is then used to generate steam for turning turbines, producing electricity that meets up to 3% of Singapore's consumer demand. This contribution is but a small fraction of Singapore's energy mix. Nonetheless, the input of biomass and biogas cannot be neglected because as R&D advances and technology develops, "energy sources which are not feasible for Singapore today may become viable in the future."[192]

C. SOLAR ENERGY

One initial challenge to solar deployment is the high upfront cost of PV systems. However, technological advancements and increases in production capacity have reduced these costs over time, resulting in payback periods as short as 7 to 10 years.[193] Figure 9 illustrates that project size, cheaper PV panels, and lower installation costs influence the shorter payback periods that make solar energy an attractive investment. Although a simple payback method is used in this calculation, many investors are comfortable with this benchmark because a break-even point of 6 to 8 years on assets with a lifespan of 25 to 30 years is viewed as a worthy venture.[194]

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[190] Ng, *Singapore, the Energy Economy*, 188.

[191] National Environment Agency, "Solid Waste Management Infrastructure"; Ng, 189.

[192] Ministry of Trade and Industry, "Energy for Growth: National Energy Policy Report," 32.

[193] Sustainable Energy Association of Singapore, "Accelerating Renewable Energy in Singapore: A White Paper," January 29, 2014, 13, https://issuu.com/sustainableenergyassociationsg/docs/whitepaper-renewableenergy-singapor.

[194] Sustainable Energy Association of Singapore, 14.

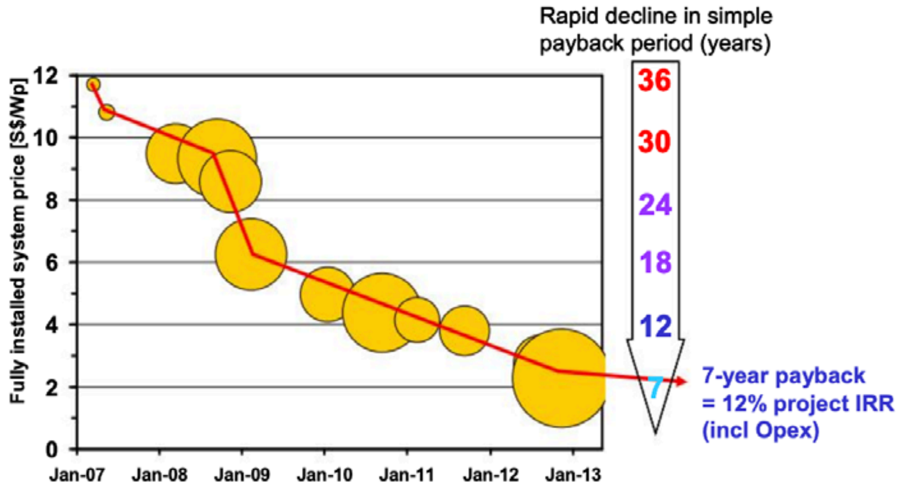

Figure 9. Payback Periods of Solar Photovoltaic Systems.[195]

Solar energy has also become financially viable due to its low risk and low maintenance costs. Most manufacturers provide 25-year warranties for their solar panels, which also means a 90% performance guarantee of rated power at 10 years and 80% performance guarantee at 25 years.[196] Moreover, solar panels do not demand extensive maintenance due to the absence of moving parts, and, generally, only require cleaning and inspection two to three times per year.[197] In the long run, a combination of the accelerated payback, long-term warranties, and modest maintenance fees alleviate the high upfront costs of PV systems.

Singapore also encourages households to send surplus energy generated by solar electric systems back to the power grid for profit, where payment is made to the user's electricity bill through monthly credits.[198] In this way, the consumer lowers his utility bill, becomes a producer of energy, and reduces his dependence on national energy resources.

[195] Source: Sustainable Energy Association of Singapore, "Accelerating Renewable Energy in Singapore: A White Paper," 13.

[196] Energy Informative, "Solar Panel Warranty Comparison," *Energy Informative* (blog), accessed February 12, 2020, https://energyinformative.org/solar-panel-warranty-comparison/.

[197] GoSolar, "Frequently Asked Questions," accessed February 12, 2020, http://www.gosolar.sg/info-faq.html.

[198] Energy Market Authority, "Guide to Solar PV," accessed February 12, 2020, https://www.ema.gov.sg/Guide_to_Solar_PV.aspx.

Another cost advantage of solar energy pertains to reducing peak demand. The Energy Market Authority (EMA) notes, "peak energy usage in Singapore—typically in the afternoons—coincides with the periods when there is the greatest output of solar energy. Lowering peak demand can potentially reduce electricity pool prices and bring system-wide benefits."[199] In other words, the more consumers tap onto their residential solar electric supply, the less they rely on the national energy grid, a scenario which lowers peak power demand and the cost of electricity.

The large-scale deployment of solar energy comes with a few limitations. First, solar energy is weather-dependent and poses the problem of intermittency.[200] For instance, despite its tropical location, Singapore's urban shading and high cloud cover affect the amount of solar radiation that reaches any given location. Likewise, the intensity of incident sunlight fluctuates within a 24-hour period and is subject to seasonal variations.[201] Sivaneasan et al. contend, "the intermittency problem of solar PV generation, typically in the range of minutes, will become very significant in Singapore as the installations of PV systems continue to increase."[202] Ultimately, the problem of intermittency exacerbates supply and demand imbalance, and therefore complicates solar energy deployment.

To adapt to the intermittency and instability of solar energy, Singapore launched its smart grid project called Intelligent Energy System (IES) in 2009.[203] A smart grid enhances conventional electricity grid security, reliability, and facilitates the integration of renewable energy resources using two-way digital communications between producers and consumers. One aspect of the IES is the system's ability to respond to erratic electricity

[199] Energy Market Authority, "Solar Photovoltaic Systems," accessed February 12, 2020, https://www.ema.gov.sg/Solar_Photovoltaic_Systems.aspx.

[200] Energy Market Authority, "Solar Photovoltaic Systems."

[201] Tilak K Doshi et al., "The Economics of Solar PV in Singapore" (Energy Studies Institute, 2011), 8, http://esi.nus.edu.sg/docs/event/the-economics-of-solar-pv_2011nov28_final.pdf.

[202] B. Sivaneasan, M.L. Lim, and K.P. Goh, "Overcoming Solar PV Intermittency Using Demand Response Management in Buildings," *Energy Procedia* 143 (December 2017): 211, https://doi.org/10.1016/j.egypro.2017.12.673.

[203] Leong Hai Koh et al., "Renewable Energy Integration into Smart Grids: Problems and Solutions — Singapore Experience," in *2012 IEEE Power and Energy Society General Meeting*, 2012, 1–7, https://doi.org/10.1109/PESGM.2012.6345679.

supply and demand flows.[204] When solar radiation is insufficient or when consumer demand is too high, the IES initiates load shedding or intentional blackouts to stabilize the grid. The system also tracks the location and extent of electrical outages, which enables it to respond promptly to restore power supply.[205] Figure 10 provides a conceptual overview of the IES program. In addition to enabling intermittent energy sources to connect to the grid, the IES encourages active consumer participation in network operations by providing them with information, choice, and control over their use of electricity.

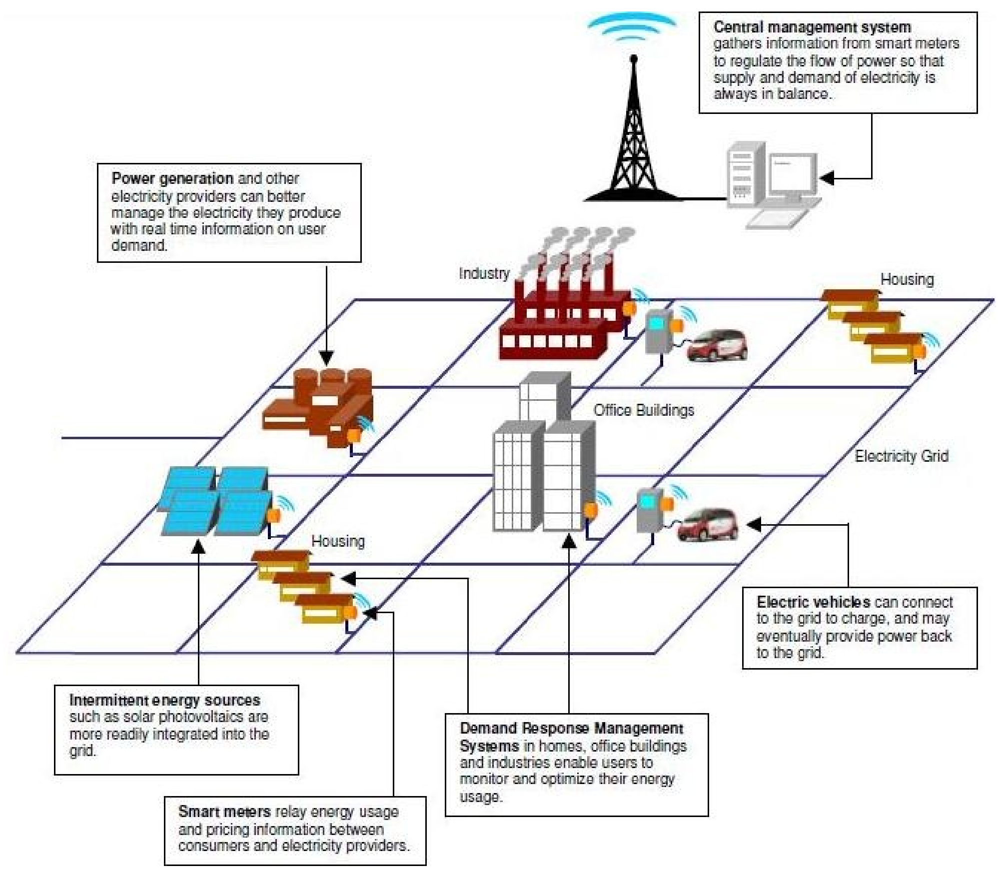

Figure 10. Intelligent Energy System Conceptual Overview.[206]

[204] Ng, *Singapore, the Energy Economy*, 206.

[205] Ng, 209.

[206] Source: Jessica Cheam, "Smart Grids Come to Singapore," Eco-Business, November 24, 2009, https://www.eco-business.com/news/smart-grids-come-singapore/.

Another constraint for renewable energy in Singapore is that land scarcity and high population density limit the amount of available surface area for solar PV installation.[207] As one of the most heavily populated cities in the world, Singapore needs approximately 6,400 hectares of land to support an estimated population boom of 5.5 million.[208] Land is a finite resource, and although Singapore has had success in its land reclamation projects, competing demands from residential housings, businesses, recreation, educational institutions, public works, etc., continue to threaten land availability for the energy industry.

Nonetheless, Singapore remains proactive in developing innovative ways to incorporate solar technology into the urban environment. One initiative is the installation of solar panels on the rooftops of residential buildings; Singapore's largest housing developer estimates that about 10,000 residential blocks can be utilized for solar generation.[209] Government buildings have also been retrofitted with solar PV systems as part of the SolarNova program launched in 2014.[210]

Moreover, the Solar Energy Institute of Singapore is exploring the use of building-integrated photovoltaics (BIPV), which integrate solar modules into the building structure to generate electricity.[211] BIPVs can be installed on curved surfaces, windows, balconies, or facades; BIPVs can also be colored or transparent to satisfy the building's aesthetics. The institute is also tapping the potential of Singapore's water reservoirs to install solar

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[207] Energy Market Authority, "Solar Photovoltaic Systems."

[208] Grace Wong, "Vertical Cities as a Solution for Land Scarcity: The Tallest Public Housing Development in Singapore," *Urban Design International* 9 (April 1, 2004): 17, https://doi.org/10.1057/palgrave.udi.9000108.

[209] Derrick Paulo and Syafiqah Omar, "From Floating Solar Farms, to HDB Rooftops: Where Singapore's Sun-Powered Future Lies," *Channel News Asia*, March 24, 2018, https://www.channelnewsasia.com/news/cnainsider/floating-solar-farm-hdb-singapore-testbed-energy-photovoltaic-10064656.

[210] Paulo and Omar, "From Floating Solar Farms, to HDB Rooftops: Where Singapore's Sun-Powered Future Lies."

[211] Solar Energy Research Institute of Singapore, "About Us," July 19, 2019, https://bipv.sg/welcome/about-seris/.

farms. With 17 water reservoirs servicing the island, there is a possibility of adding a few hundred megawatts of power to Singapore's energy pool.[212]

Last but not least, Singapore is developing a plan to outsource solar energy from Australia, a project which will transmit electrical power via 3,800 kilometers of undersea cable.[213] The project is expected to deliver three gigawatts of power, equivalent to one-fifth of Singapore's electricity supply. When complete, the undersea power line will be the longest in the world, surpassing by five times the 720 km power cable that connects Norway and the United Kingdom.[214] David Griffin, the chief executive of the company behind the project, estimates that the venture will be complete by 2027.[215] All of these developments in Singapore's solar energy industry feature the country's wealth of technology, research expertise, and skilled workers and technicians. These will help further the country's energy and economic goals, despite the apparent limitations brought by geography and lack of indigenous resources.

D. BIOFUELS

Singapore has a well-developed waste collection and disposal industry. The government has adopted a four-part strategy for sustainable waste management which involves: (1) reduce and reuse, (2) recycle, (3) waste treatment, and (4) landfill and ash management.[216] After waste is segregated and recyclables are sorted, the remaining waste is sent to WTE plants for treatment and incineration. This process enables the efficient recovery of energy as biofuels, which also minimizes the use of landfill space. Ash and non-incinerable wastes are then sent to Pulau Semakau, an off-shore landfill for final

[212] Paulo and Omar, "From Floating Solar Farms, to HDB Rooftops."

[213] Sun Cable Singapore, "Renewable Energy for Singapore and Australia."

[214] Douglas Broom, "Australian Solar Could Power Singapore within a Decade," World Economic Forum, August 6, 2019, https://www.weforum.org/agenda/2019/08/australian-solar-power-singapore/.

[215] Adam Morton and Ben Doherty, "Billionaires Invest in Giant Australian Solar Farm to Supply Power to Singapore," *The Guardian*, November 20, 2019, sec. Environment, https://www.theguardian.com/environment/2019/nov/20/billionaires-invest-in-giant-australian-solar-farm-to-supply-power-to-singapore.

[216] National Environment Agency of Singapore, "Waste Management," accessed February 14, 2020, https://www.nea.gov.sg/our-services/waste-management/overview.

disposal.[217] Consequently, the total waste volume will have already been reduced by 90% by the time the ash residue reaches Pulau.

Singapore's total solid waste in 2018 reached 7.7 million tonnes and from these, about 350,000 tonnes generated by wood and horticulture were sent to biomass power plants for conversion to fuel.[218] Table 3 shows the 2018 composition of waste in Singapore, highlighting waste that was recovered for conversion to biomass and biogas, which is equivalent to about 3% of the country's energy needs.

Table 3. Waste Composition in Singapore, 2018.[219]

Waste Type	Total Disposed (tonnes)	Total Recycled (tonnes)	Total Generated (tonnes)	Recycling Rate
Construction debris	6,600	1,617,900	1,624,500	99%
Ferrous metal	9,300	1,260,200	1,269,500	99%
Non-ferrous metal	1,700	169,600	171,300	99%
Used slag	2,300	178,900	181,200	99%
Scrap tyres	3,200	29,300	32,500	90%
Horticultural	**151,100**	**370,100**	**521,200**	**71%**
Wood	**131,800**	**187,900**	**319,700**	**59%**
Paper/Cardboard	467,400	586,400	1,053,800	56%
Glass	51,500	12,200	63,700	19%
Food	**636,900**	**126,200**	**763,100**	**17%**
Ash and sludge	215,200	24,600	239,800	10%
Textile/Leather	205,800	14,000	219,800	6%
Plastic	908,600	40,700	949,300	4%
Others (stones, ceramic, rubber, etc.)	274,300	11,400	285,700	4%
Total	3,065,700	4,629,400	7,695,100	**60%**

Note: Biomass feedstock is highlighted in red. Biogas feedstock is highlighted in blue.

Previous analyses have shown that, the amount of waste generated in Singapore is insufficient for biogas production and is unlikely to meet the country's energy demands.[220] These studies indicate that Singapore would have to import a significant amount of biomass

[217] National Environment Agency of Singapore, "Waste Management."

[218] National Environment Agency of Singapore, "Waste Statistics and Overall Recycling," accessed April 4, 2020, https://www.nea.gov.sg/our-services/waste-management/waste-statistics-and-overall-recycling.

[219] Source: National Environment Agency of Singapore, "Waste Statistics and Overall Recycling."

[220] Quek et al., "Challenges in Environmental Sustainability of Renewable Energy Options in Singapore," 392.

waste to meet 97% of the population's electricity needs, which is equivalent to about 158–357 million tonnes of waste annually. This is an impractical option for a country with limited land and a dense population. At best, the maximum contribution of biomass and biogas to Singapore's electricity mix is 5.1%.[221]

Chicken manure is another locally available waste that is being utilized to produce biogas. Through anaerobic treatment, methane is recovered from chicken waste, which is then used for electricity generation. This electricity powers the farm's infrastructure, allowing it to be self-sufficient and sustainable, and resulting in energy savings costs of approximately SGD$60,000 per month.[222] Singapore has three chicken farms that continue to expand operations to minimize dependence on poultry imports. Collectively, the farms are expected to generate 150,000 tonnes of annual organic waste by 2025, equivalent to approximately 50 Gigawatt-hours of electricity which could sustain farm operations.[223]

Although the biofuels industry did not take off as it was envisioned in 2007, Singapore remains enthusiastic that its current bio-renewable projects will contribute to the energy security, sustainability, and equity that the country needs. For example, as seen in Table 4, the country continues to operate a few biomass and biogas power plants, with more under contract for development. The ongoing operation of these power plants indicates that the setbacks to the biofuels industry as mentioned earlier have not deterred Singapore from supporting the penetration of biofuels in its energy landscape.

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[221] Quek et al., "Challenges in Environmental Sustainability of Renewable Energy Options in Singapore," 292.

[222] Liew Kian Heng, "Bio Gas Plant Green Energy from Poultry Wastes in Singapore," *Energy Procedia* 143 (December 1, 2017): 440, https://doi.org/10.1016/j.egypro.2017.12.708.

[223] Sustainable Energy Association of Singapore, "Accelerating Renewable Energy in Singapore," 24.

Table 4. Biomass and Biogas Power Plant Status in Singapore.[224]

S/N	Type of biorenewable energy	Organisation	Location	Status	Notes
1	Biomass	ecoWise Group	Sungei Kadut	In operation (Co-generation)	First CDM project in Singapore registered with UNFCCC
2	Biomass	Gardens By The Bay & ecoWise Group	Marina South	In operation (Tri-generation)	15-year DBO renewable energy supply to Garden's conservatory
3	Biomass	CGNPC Solar-Biofuel Power (S'pore)	Shipyard Crescent	Under development	First foreign owned biomass plant cum solar power in Singapore
4	Biomass	Sembcorp Industries	Jurong Island	Constructed	Supplying to Singapore petrochemical hub
5	Biomass	Kim Hock Pte Ltd	Sungei Kadut & Jurong	Constructed	-
6	Biogas	Public Utilities Board waste water anaerobic digestion biogas plants	Changi WRP, Jurong WRP, Ulu Pandan WRP & Kranji WRP	In operation	Estimated 7 MWe* of power from 120'000m³/day biogas used in operation of plants. (source: PUB)
7	Biogas	Chicken waste to biogas combined heat & power CHP	3 farms	Under development	Estimate 490 tonnes/day by 2020, to generate ~50GWh/yr, plus approx 10MWth* output
8	Biogas	IUT Global Food waste to energy	Tuas	Closed down	4.5 MWe & 5 MWth* capacity closed due to feedstock supply issues.

As to the financial viability of biofuels, the Sustainable Energy Association of Singapore (SEAS) estimates a 16% to 22% internal rate of return from the industry.[225] The SEAS also cautions that biofuels may have steeper financing costs compared to the solar alternative as a result of feedstock supply issues. Nonetheless, one potential solution to reduce these costs is by co-locating biofuel power plants at material recovery facilities.[226] Biogas from chicken manure is instructive—by producing, processing, and utilizing waste on-site, the cost of purchasing raw materials is eliminated, ultimately resulting in lower capital costs. For example, Figure 11 shows a farm-site blueprint that has its biogas power

[224] Source: Sustainable Energy Association of Singapore, "Accelerating Renewable Energy in Singapore," 18.

[225] Sustainable Energy Association of Singapore, 25.

[226] Sustainable Energy Association of Singapore, 26.

plant in proximity to the waste recovery and treatment plants, a layout which helped the company reduce its transmission and distribution costs.

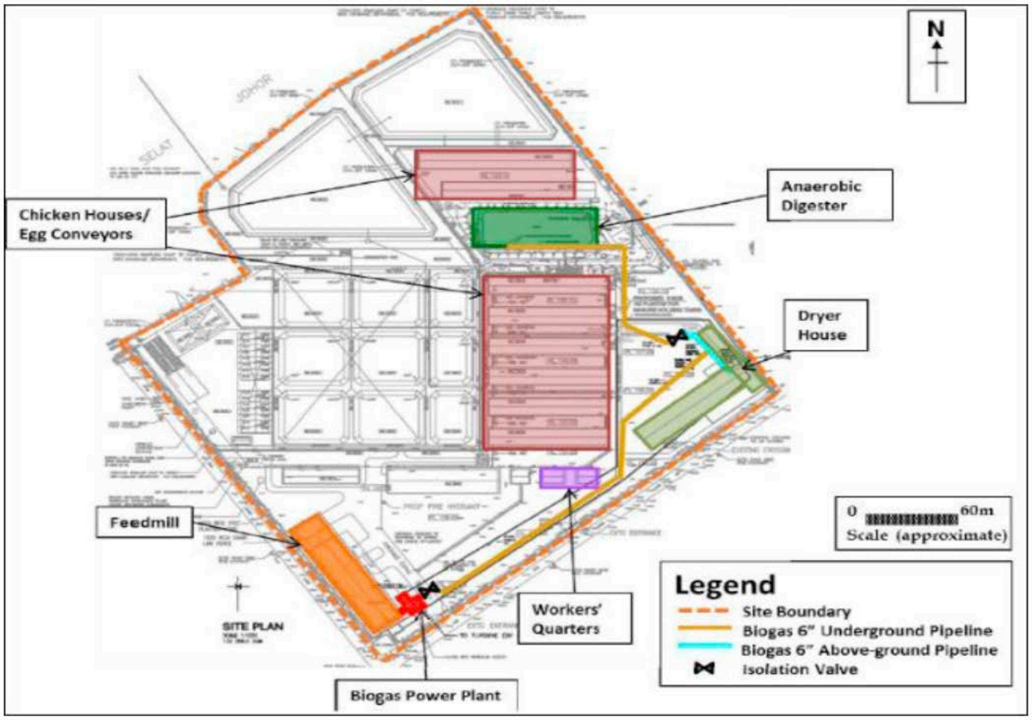

Figure 11. Lim Chu Kang Farm-Site Layout.[227]

Beyond the potential return on investment of energy recovered from waste products are other non-financial benefits worth consideration. According to SEAS:

> Since a biomass co-generation plant is like a mini-power plant involving almost all disciplines of engineering and with high degree of automation, investments into these projects will create rewarding employment for PMETs [professionals, managers, executives, and technicians]. Singapore can build up a talent pool in the bio-energy sector.[228]

[227] Source: Heng, "Bio Gas Plant Green Energy from Poultry Wastes in Singapore," 437.

[228] Sustainable Energy Association of Singapore, "Accelerating Renewable Energy in Singapore," 27.

Likewise, Singapore's Minister for the Environment and Water Resources estimates that the industry is expected to generate about 1,000 jobs in the next five years and around 2.2 million jobs by 2030 for the region.[229]

In addition, the zero-waste approach of biofuel power plants will help control Singapore's urban problems such as the expanding landfill dilemma. WTE systems greatly reduce the amount of municipal waste that are transported to landfills, maximizing waste yard capacity in the land-scarce country.[230] To some extent, the cost reductions associated with waste transportation and efficient use of landfills offer another side benefit. Finally, Singapore's biofuel industry game plan "can be exported to other countries (such as China, ASEAN and India) where there is abundant biomass waste and a great need for electricity, thermal heat and air-conditioning."[231] This initiative could be an opportunity for Singapore to showcase its knowledge and expertise in the energy industry despite its geography and resource constraints.

E. FINDINGS

Similar to the previous chapters on hydrocarbons and nuclear energy, Singapore's renewable energy industry is evaluated using a SWOT analysis to derive policy implications and to recommend avenues for improving future performance. The SWOT analysis of the renewable energy framework is as follows:

One strength of the renewable energy industry is the promotion of energy diversification which ultimately reduces supply risks, particularly for a country that relies heavily on imports. Second, it makes energy more accessible and affordable by enabling the consumers to become producers of solar energy with the ability to sell the surplus back to the grid. In addition, renewable energy technology has grown more viable over the past few decades due to technological innovation and investments in R&D. Most importantly, the government has set clear, actionable, and measurable goals regarding the future of solar

[229] Xinhuanet, "Singapore to Benefit from Clean Energy Investments: Minister," October 31, 2018, http://www.xinhuanet.com/english/2018-10/31/c_137571569.htm.

[230] National Environment Agency, "Solid Waste Management Infrastructure."

[231] Sustainable Energy Association of Singapore, "Accelerating Renewable Energy in Singapore," 27.

energy, a detail that has been lacking in the policy documents of the other energy subsectors. One recommendation, however, is for Singapore to impose mandatory regulations for retailers to source a percentage of total electricity sales from renewable energy supplies based on a fixed timeline.[232] In this way, Singapore can increase its uptake of renewable energy and reduce its dependency on fossil fuels.

The weaknesses of the renewable energy industry are mainly due to the limitations brought by Singapore's geography. Especially for solar energy, problems of intermittency compromise electrical grid stability. Land shortage also constrains solar PV deployment. Nevertheless, Singapore makes a conscious effort to manage these geographic disadvantages. For example, the smart grid project upgrades electricity delivery systems through digital communication, which allows rapid response to fluctuating energy supply and demand. In this way, power plants can promptly intervene to ensure an uninterrupted power supply. Next, land scarcity is mitigated by utilizing all available surfaces for solar PV installation, such as the roofs and facades of residential and government buildings, water reservoirs. More remarkably, Singapore is exploring the use of trans-oceanic subsea cables to import solar energy from Australia.

With regard to opportunities, Singapore could utilize its wealth of technology, research expertise, skilled workers and technicians to secure the country's position as Asia's leading clean technology hub. Next, the industry could broaden opportunities for economic growth by attracting foreign investors and increasing employment for the PMET labor group. Through the biofuels industry, Singapore could also fully realize its zero-waste ambitions and maximize its landfill usage. Lastly, the renewable energy industry could be an avenue for promoting corporate social responsibility (CSR). One focus of CSR is incorporating sustainable development into a company's business strategy.[233] Renewable energy can help reduce a company's carbon footprint, setting the bar for responsible social norms and benefitting the company and society in general.

[232] Sustainable Energy Association of Singapore, "Accelerating Renewable Energy in Singapore," 33.

[233] Skye Schooley, "What Is Corporate Social Responsibility," *Business News Daily*, April 22, 2019, https://www.businessnewsdaily.com/4679-corporate-social-responsibility.html.

Threats to the renewable energy landscape include the risks involved with feedstock supply to generate biofuels. In the first place, Singapore's insufficient biomass waste means that the government would have to consider importing waste from outside the country to generate significant amounts of energy. There are also transmission and distribution costs associated with feedstock supply, increasing the capital costs associated with operating bio-renewable power plants. Nonetheless, Singapore attempts to ease these expenses by co-locating biofuel power plants with material recovery facilities.[234] Thus far, Singapore's poultry farms have adopted this concept and have seen financial gains.

It is unrealistic to import a million tonnes of biomass waste when there is a shortage of land options, but it should not be a limitation to pursue renewable energy goals. According to SEAS, Singapore can do two things: first, introduce "acceptable standards for biomass power plants such as minimum system efficiencies to fully recover the inherent energy from limited biomass fuel" and second, "allow other industrial waste to be used as supplementary fuel to the power plants to enhance energy efficiency and reduce the quantity of biomass required."[235] With collaboration among the government, private sector, and research institutes, Singapore can find innovative solutions to its urban and energy problems.

Up to this point, this thesis has discussed the history, policies, and outlook regarding Singapore's three energy subsectors and how each is enabling the country to manage the three competing ends of energy security, economic equity, and environmental sustainability. The final chapter synthesizes the findings of this research and provides final recommendations to help Singapore shape its future energy policies.

[234] Sustainable Energy Association of Singapore, "Accelerating Renewable Energy in Singapore," 26.

[235] Sustainable Energy Association of Singapore, 32.

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V. CONCLUSION

The Singapore economic experience is one of the most impressive stories of poverty to plenty. From a sleepy fishing village during the pre-British Empire era, the country now ranks among the richest economies in the world, owing to structural reforms and political-economic choices made by the government following its independence from British rule. By the same token, the energy industry has contributed greatly to Singapore's meteoric economic growth, a remarkable achievement considering the country's lack of indigenous energy resources. Unfortunately, the pursuit of economic growth through the energy industry involves trade-offs in the areas of energy security and environmental sustainability. Energy independence is not a one-dimensional end state—the process involves carefully managing the three competing ends of what is known as the energy trilemma.

As demonstrated in this thesis, while Singapore has consistently performed well over the past few decades in the realms of energy equity and environmental sustainability, the country has struggled with energy security due to its heavy reliance on imported fuel sources. Singapore imports most of its energy from Malaysia and Indonesia, a situation that makes the country vulnerable to a number of supply and price risks such as geopolitical conflict, social unrest, accidents, and natural disasters. Nonetheless, Singapore strives to expand its domestic energy production and enhance its energy independence through the three energy subsectors of hydrocarbons, nuclear energy, and renewable resources.

Equally important, Singapore simultaneously addresses the demand side of the problem. The government has made strides in efficiency by liberalizing the electricity market, which in turn encourages the prudent use of energy resources. In addition, Singapore has adopted the use of more efficient technology—from CCGTs and solar PVs, to optimizing the design of buildings and vehicles, to the introduction of smart grid systems and the implementation of the carbon tax. Altogether, these efforts in efficiency help reduce energy usage and eliminate energy wastage, while delivering the same level of service to the population.

This thesis concludes by returning to the research questions posed in Chapter I. First, in what way is Singapore's current energy strategy helping the country achieve greater energy security? Second, how might Singapore modify its energy policy given that international competition for energy sources has intensified? To the first question, our findings suggest that Singapore need not possess a large endowment of domestic energy resources to improve its energy security. Singapore approaches energy security through partnerships with international players to expand its energy access, as demonstrated by the country's venture into liquefied natural gas that has opened the country to a variety of fuel sources beyond Asia. Similarly, Singapore's international partnerships make the import of renewable energy feasible, as illustrated by the plans to source solar energy from Australia. Furthermore, Singapore's cooperation with ASEAN member states in terms of advancing the region's nuclear energy infrastructure indicates a strong commitment toward greater energy security.

The findings also reveal the importance of Singapore's whole-of-government approach in pursuing energy security. This is a necessary strategy because the energy trilemma is an indivisible issue that must be confronted as a system rather than as independent components. The whole-of-government approach facilitates the sharing of objectives across organizational boundaries, which results in an integrated government response to the country's energy issues. Of note, the coordinated and consistent support across multiple agencies for solar energy has produced coherent policies, aggressive R&D investments, and actionable and measurable goals, which have made the renewable energy industry a much more viable option now compared to the last few decades.

Although Singapore does not have formal plans for the nuclear power industry at the moment, it does not rule out nuclear energy in its future energy landscape. In fact, the government has allocated significant resources to develop the country's nuclear knowledge base. In the same way, Singapore continues to support the biofuels sector despite its initial difficulty in penetrating the energy landscape. These two examples emphasize that technical innovation and perseverance are Singapore's strongest characteristics which help bridge the gap between energy deficiency and energy independence.

With regard to the increasingly competitive international energy environment, Singapore need not take drastic measures to modify its current energy framework. Instead, Singapore should focus on managing its foreign relations, both bilaterally and multilaterally. As Henry Kissinger points out, “to a certain extent the new ‘great game’ has already begun. Access to energy today [is] not only a purely economic but also political problem. As long as resources are limited and demand is still increasing, consumerist countries should come to an agreement before the competition leads to serious tensions.”[236] In other words, a nation’s survival in a world of heightened energy demands will depend on positive relations between countries that participate in the global energy system.

The world has become much more complex due to globalization, which means that if Singapore’s economy were to falter due to lack of energy, other countries could also feel the negative impact of this downturn. In an interconnected and increasingly competitive world, energy security will thus depend on the ability of nations to cooperate to ensure that each is able to find the resources it needs to survive. While it is natural for countries to seek what is best for their own security, unilateral measures must be replaced with multilateral strategies if true energy security is to be attained. Global linkages have made nationalistic conceptions of energy security irrelevant. To this end, Singapore’s leaders must quickly recognize that the concept of energy security is evolving. This means that now is the time to shift Singapore’s ideals from energy independence to energy interdependence.

[236] SPIEGEL International, “Henry Kissinger on Europe’s Falling out with Washington”, October 10, 2005, https://www.spiegel.de/international/spiegel/spiegel-interview-henry-kissinger-on-europe-s-falling-out-with-washington-a-379165.html.

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